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REPORT ON THE WORK OF THE BARTOL RESEARCH FOUNDATION, 1938–39.*

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BY

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INTRODUCTION.

As is customary with a scientific organization such as the Bartol Research Foundation, which has acquired a certain responsibility, not only to itself, but to its sister institutions throughout the country and throughout the world, our activities during the year have been divided in a general way into three categories. In the first, we have original investigation involving the discovery of new phenomena. In the second, we have been concerned with the correlation of the various phenomena in our field, with the remoulding and adjustment of the fundamental bases of our science to a greater clarification of what it is that we are talking about; and we have been concerned, moreover, with the extension of the implications of science to other fields. In the third category we have activities concerned with collaboration with our colleagues from other institutions and with a comparison and sharing of ideas.

In the third category fall the thirty-three or more papers which have been published, or presented before learned so-

* Presented at the Stated Meeting held on April 19, 1939.

(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors in the JOURNAL.)

cieties, during the year which has elapsed since my last report, and in particular the participation by invitation of practically all of our members in the cosmic-ray symposium held under the auspices of the University of Chicago last summer. In the second category fall, partially in published and partially in unpublished forms, certain extensions of fundamental concepts in the field of atomic structure and in the philosophy of science, together with discussions of the extension of science to human affairs and the like. It is the first category which comprises the main subject of my address this evening.[1]

COSMIC-RAY PHENOMENA.

In meeting new people, our two main interests are who they are and what they do, and so it has been with cosmic rays. Within the last decade or so, we have learned with ever-increasing certainty who they are. Starting with the concept of one type of entity, the cosmic-ray family has increased so that we now find all of the fundamental particles of atomic structure playing some rôle in its activities. Indeed, it has been through the study of cosmic rays that some of these particles have been discovered. I refer in particular to the positive electron and to the mesotron, a particle intermediate in mass between the electron and the two thousand times heavier proton, a particle about two hundred times as heavy as the electron. It is illustrative of the close interlocking of the various branches of science that the discovery of these two particles in the field of cosmic rays has illuminated in untold measure our understanding of phenomena in fields of science having no immediate connection with cosmic rays.

And so we have learned much concerning the genealogy of those various things which we observe as cosmic rays; and we have learned equally much concerning the second point of interest—what the cosmic rays do.

COSMIC-RAY SHOWERS.

One of the chief activities of cosmic rays is that of giving rise, on passing through matter, to showers of other rays which

[1] In describing the various investigations, footnote references will be attached in those cases where the investigations referred to have already reached the stage of publication.

are in many respects similar to the original rays themselves. There is, in fact, considerable evidence in favor of the view that most of the rays which we observe in the atmosphere are secondary rays of this kind, which represent the progeny, removed sometimes by many generations from the original radiation which enters the atmosphere from outer space.

The quantum theory of atomic structure has led us to the concept of a situation in which an electron, in passing through a piece of matter, loses a certain amount of its energy by radiation, which energy becomes subsequently materialized into a positive and a negative electron, so that at this stage we have three such charged particle entities. Each of these entities can repeat the process so that, from the single entering electron ray, many other rays result. It has been customary to assume that a large part of the cosmic radiation observed in the atmosphere originates in this manner.

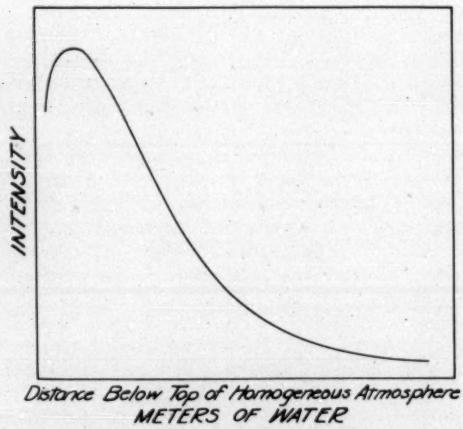
As we descend into the atmosphere from above, the number of rays to be found increases by this multiplicative process and would continue so to increase except that those of the progeny which are born with little energy are soon lost by the dissipation of that energy in collision with the molecules of the air and in the breaking of them up into what are called positive and negative ions. There is, in fact, in the atmosphere a birth rate and a death rate of rays. As we descend from the top, we find that at first the birth rate exceeds the death rate and the number of rays increases with depth. On further descent, however, we reach a point at which the two rates are equal and the number of rays remains constant with depth for a little distance. At still lower depths, the death rate exceeds the birth rate, and from here on the density of the rays diminishes continually as we descend. The net result of these considerations is to provide a situation such as that represented in Fig. 1, where the number of rays passing per second—let us say, through a fixed vertical tube—is plotted against the depth from the top of the atmosphere, estimated in terms of what it would be if the atmosphere were condensed to a liquid and constrained to assume the density of water.

It is, of course, well recognized that the story above sketched does not represent the whole story of the cosmic

rays in the atmosphere and that there are rays other than electrons—in particular the rays which I have referred to as mesotrons—which play an important part. However, it has been customary, until recently, to assume that all of the pure electron rays to be found in the atmosphere have originated in the manner described.

Evidence for the Origin of Electrons from Mesotrons.—Last year, I presented evidence from experiments performed by

FIG. 1.



Mr. W. E. Ramsey and myself [2] in a mine 100 feet deep that there were electrons which had arisen in other ways, and in particular from the mesotrons themselves. Now, Dr. and Mrs. C. G. Montgomery,[3] by a different kind of procedure, have cemented this conclusion. The procedure will be understood from the following:

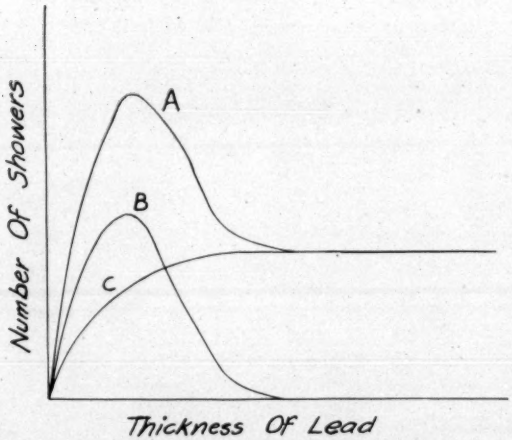
Suppose we take a piece of lead and allow rays of a definite energy to fall upon it. These rays will, by the multiplicative

[2] W. F. G. Swann and W. E. Ramsey, *Phys. Rev.*, **54**, 229 (1938); also W. F. G. Swann, "Report of the Work of the Bartol Research Foundation, 1937–38," JOUR. FRANK. INST., **226**, 441 (1938).

[3] C. G. and D. D. Montgomery, *Phys. Rev.*, **55**, 676 (1939).

process, produce showers from the other side of the lead, and from the theory we can calculate the relative numbers of showers of different sizes. If we have a number of electrons falling upon the lead, each energy group will produce a distribution of shower sizes characteristic of the energy of the group. The question arises as to whether, by examining the net complicated distribution of shower sizes, we can work back and ascertain the energy distribution in the rays which

FIG. 2.

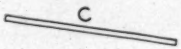


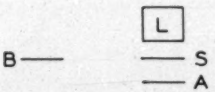
produced the showers. The answer which Dr. and Mrs. Montgomery have given is in the affirmative. By examining the shower distributions at the top of Pike's Peak and at sea level, they were able to calculate the distribution of energy in the electrons in the atmosphere at these two altitudes. We may now ask the question as to whether the distribution so found at sea level is the kind of distribution which could, by the multiplicative process in the atmosphere, have grown out of the distribution found at Pike's Peak. The answer given by the experiments and calculations of the Montgomerys is to the effect that it is not. It was thus necessary to conclude

that electrons must make their appearance in the atmosphere by processes other than those provided by multiplication from other electrons. In other words, as far as electrons are concerned, the facts are contrary to the hypothesis of complete inbreeding. A new strain must be introduced from somewhere and that somewhere is, presumably, the mesotrons.

On the Nature of the Rays which Produce Showers.—I now turn to another aspect of shower production. Suppose that we expose a piece of lead to cosmic radiation and count the number of showers which emerge from its lower side in a given time. Suppose we plot this number against the thickness of

FIG. 3.





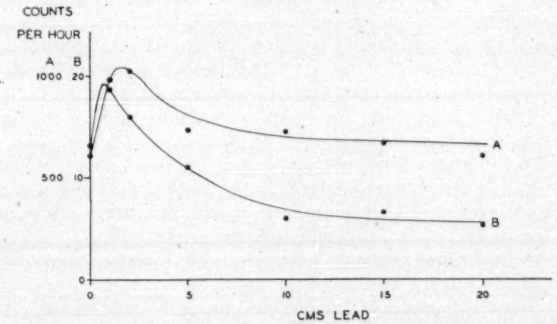
the lead. Then we obtain a curve such as Fig. 2, curve *A*, which is called a Rossi curve because B. Rossi first obtained it. Now the multiplicative shower theory as applied to electrons producing showers would lead to a curve of the form Fig. 2, curve *B*, characterized by the fact that it falls to practically zero at a thickness of a little more than 10 cm. of lead. We can, however, construct such a curve as *A* out of a curve like *B* and another curve like *C*. It has, therefore, been customary to assume that the curve like *C* has meaning as representative of the shower production by rays which are not electrons and are, therefore, presumably mesotrons. Now Dr. and Mrs. Montgomery [4] and Mr. Ramsey have performed

[4] C. G. and D. D. Montgomery, JOUR. FRANK. INST., **226**, 623 (1938).

an experiment with the idea of showing that showers are produced by at least two mechanisms characteristic of the nature of the rays which produce them. The experiment may be understood from the following:

At *C*, Fig. 3, we have a fixed plate of lead; *L* is another plate of lead whose thickness can be varied. Below *L* is a tray of Geiger counters, *S*, and below *S* is another tray of counters, *A*. These *S* and *A* counters are arranged to record only when at least one counter in *A* and two in *S* discharge. Under these conditions, we know that a shower has come from *L*. Using the apparatus in this way, we may plot the number

FIG. 4.



of counts per hour against the thickness of the lead, and by so doing we obtain a curve such as *A*, Fig. 4, which is the ordinary Rossi curve. The showers in this case are produced in *L* by all of the classes of shower producing rays which fall upon it.

Suppose that we now move counter tray *A*, Fig. 3, to the position *B*, still with matters arranged so that a record will be made only if two or more counters from *S* and at least one from *A* discharge. Under these conditions, we know that the ray which initiates the shower in *L* is accompanied by another ray which operates the counter tray in position *B*, so that both of these rays are presumably shower rays which have come, again presumably, from the piece of lead, *C*. Now such information as we have concerning shower rays leads us to

believe that they are electrons or photons, and we might expect, therefore, that all of the showers recorded from *L* for the position *B* would be showers produced by electrons or photons. On plotting the number of these showers against the thickness of the lead, we might expect to obtain a curve such as *B*, Fig. 2. Now such a curve was not, in actuality, found. The curve found was *B*, Fig. 4, and the significance of this result is two-fold. In the first place, since *B*, Fig. 4, is definitely different from *A*, it has been shown possible to divide the shower producing rays into two categories distinct as regards their shower producing characteristics. In the second place, contrary to expectations, the shower producing rays of the class which are themselves shower rays do not operate according to the quantum theory for electron shower production, which would have made them give a curve such as *B*, Fig. 2, instead of *B*, Fig. 4. The inference is either that the shower rays contain rays other than electrons or photons, or that there is something incomplete about the quantum theory of shower production in lead by electrons.

Experiments Concerned with the Life of the Mesotron.—The history of the mesotron presents an interesting example of the interplay between theory and experiment in modern physics. A few years ago a Japanese physicist, H. Yukawa, while meditating upon the energy which binds together neutrons and protons in the nucleus of the atom, found that in terms of the properties of these two entities alone he was unable to account for the binding energy which experiment revealed to be there. By the invocation of a third particle, however, with suitably chosen properties, it was possible to provide for the binding energy in a manner which was harmonious with the general system of law structure in terms of which physicists today think of the nucleus of the atom. The principle property of this newly postulated particle was that it should have a mass about 200 times that of the electron. This particle having been introduced, Yukawa sought to utilize its services in easing the explanation of other nuclear phenomena, and in particular the phenomenon associated with the emission of beta particles from the nucleus of the atom. In this service, it was necessary to invoke for the particle an additional property, a property, however, which was not inharmonious

with the properties necessary for its other duties. This new property was the privilege of dying at any time and the certainty of dying some time. The ambiguity involved in the word "privilege" implies that there is no one age of death for these particles, but only an average life, a "mean life," to use the customary mode of expression. It is true that during its life the particle does little else but dissipate its energy in disrupting the molecules of any substance through which it passes, producing ions, so in another sense it may be said to lead a "*mean life*"; but that is not the official interpretation of the designation.

Now when cosmic-ray phenomena revealed that particle which is now called the "mesotron," and by some the "meson," and required that it should have a mass about 200 times that of the electron, it was natural to seek to associate this mesotron with the particle theoretically postulated by Yukawa. This association enriched the mesotron of cosmic rays with the additional properties other than large mass with which cosmic-ray phenomena had endowed it. In particular, it enriched it with a "mean life" and, ever on the lookout for service from its particles, physics sought to invoke the aid of this mean life in the service of explaining further cosmic-ray phenomena. In fact, such slave-drivers are the physicists of today that the new particle was put to work before it had been christened. Its first work was done under the makeshift name of "heavy particle." Then, for a short time it enjoyed the names Yukon and Barytron. Finally, benediction has been placed by some on the term "Mesotron," and by others on the term "Meson."

Now there is one rather simple cosmic-ray phenomenon which has been rather difficult to explain in ordinary ways. This phenomenon concerns the fact that, on a basis of natural assumption, we should expect the absorption of those cosmic rays which we associate with mesotrons to be proportional to the density of the medium through which they pass, regardless of the nature of the medium. However, it is known that water absorbs these cosmic rays to a lesser extent in comparison with air than would be expected from its far greater density. It appears, in fact, as though there is some additional agency responsible for the apparent absorption of these

cosmic rays, an agency which is not affected at all by differences in density or, at any rate, which is not affected to an extent proportional to the density. Such an additional apparent absorption can be understood if we picture the mesotrons as having a finite mean life which is independent of the medium through which they are passing. In such a case the absorption in water, for example, will be affected much less, relatively, by this mean life than will the absorption in air, because the time taken to pass through a given thickness of water is about 1000 times smaller than the time taken to pass through a thickness of atmospheric air, which is equally absorbing as regards the ordinary processes of absorption. It will readily be seen that by utilization of the difference between the absorbability of cosmic rays in air and water it should be possible to determine what the mean life of the mesotron must be in order to harmonize the results. From such considerations, Kuhlenkampf, Euler, and Heisenberg arrived at a value of about 3×10^{-6} second for the average life which the mesotron enjoys. Unfortunately, such a life makes the mesotron a regular Methuselah as compared with the life with which Yukawa's considerations had endowed it for its other duties in respect of radioactivity. There is, in fact, a discrepancy of 1000 between the lives as determined in the two ways. While such a discrepancy is far too large to be accounted for by any supposed error in the cosmic-ray measurements, it seemed, nevertheless, of interest to repeat, as part of one program, the cosmic-ray measurements necessary to calculate the mean life which is consistent with cosmic-ray phenomena. To this end, Dr. T. H. Johnson and Mr. M. A. Pomerantz[5] decided to compare the cosmic-ray absorption in thicknesses of air and water which were equivalent as regards the elementary theory of absorption which neglects the mean life phenomenon. A thickness of water which is equivalent in this sense to the vertical thickness of the atmosphere is a thickness of about 30 feet of water, so that the water tank, Fig. 5, which I had constructed last year for investigations concerned with mesotrons, provided a convenient means. Using a Geiger counter telescope system, Fig. 6, the absorption in the vertical column of water was

[5] T. H. Johnson and M. A. Pomerantz, *Phys. Rev.*, **55**, 104 (1939).

compared with the absorption in an equivalent mass thickness of air, the latter being obtained by making vertical measurements in air, and measurements inclined at 60° to the zenith. The results led to a mean life of 2.5×10^{-6} second.

In speaking of the mean life of a mesotron, one must be careful of one point. According to the theory of relativity, if I travel through space on a rocket ship with a velocity com-

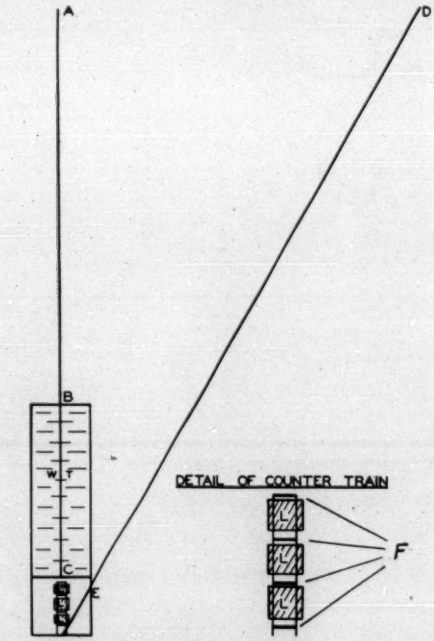
FIG. 5.

Tank in which apparatus is installed. The upper part is filled with water. The apparatus is in the lowest 12 foot section.

parable with that of light, and if I carry with me a watch to see how long I live, my watch will not agree with the timepieces of those who are left at home. The insurance company which pays my annuity into the bank will be very angry, because if, by my watch, I die at the age of 60, they, in terms of their clocks at home, will find me living longer to an extent which is greater and greater the closer the approximation of my velocity to that of light, so that if, in fact, I travel actually with the velocity of light, I shall live for ever on the books of

the insurance company, even though I die at 60 in terms of my own scale of time. The mean life of the mesotron to

FIG. 6.



WT represents the water tank containing 30 feet of water, equivalent in absorbing power to one atmosphere of air. The train of four trays of counters *F*, is shown underneath, with blocks of lead, *L*, interposed to exclude the less penetrating radiation, and thus render the instrument sensitive only to mesotrons. When the apparatus was vertical, the intensity of mesotrons which had traversed one atmosphere of air, *AB*, plus one atmosphere of water, *BC*, was recorded. When the apparatus was inclined at an angle of 60° from the vertical, the intensity of mesotrons which had traversed two atmospheres of air, *DE*, was recorded. Inasmuch as the geometrical path length, *DE*, exceeded *ABC*, the time required for the mesotrons to reach the apparatus in the inclined direction was longer. This permitted a greater number of mesotrons to die during the traversal of the longer path, resulting in a lower intensity. From the ratio of the intensity in the inclined direction to that in the vertical, the mean lifetime of the mesotron is calculated as 2.5 microseconds.

which I have referred, is the life as measured by a timepiece which is at rest in relation to the mesotron. Since the mesotrons which we observe are all moving with velocities

comparable with that of light, the calculation of the mean life when at rest involves an allowance for the velocity. Indeed, if we should separate mesotrons of different velocities and measure their mean lives, we should expect to find different values which would all correct to the same value, however, when the correction required by the theory of relativity was applied.

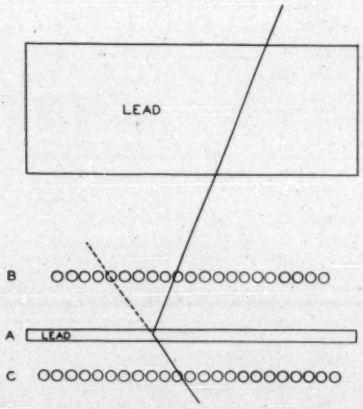
In order to test the harmonization of all of these matters, Dr. Johnson and Mr. Pomerantz are now measuring the mean life of the mesotron for different energy conditions. For convenience, the function of the water tank is replaced by an equivalent thickness of lead. Then, in addition to this lead and below it, there is another piece of lead whose thickness can be varied. This second piece of lead acts as a kind of filter, which filters out from the low energy range of the rays an amount depending upon its thickness and leaves, therefore, for measurement the rays above any given assigned energy. By taking the differences of results of experiments with two different thicknesses of this filtering lead, we confine our observations to rays which lie between fixed limits of energy, centering about a mean energy characterized by the average thickness of the lead in the two groups of experiments.

The Death of the Mesotron.—It is of interest to contemplate what happens when the mesotron dies. Even when it is at rest it has a mass equivalent to that of about 200 electrons. Modern atomic theory, which recognizes the interchangeability of mass and energy, would tell us that if this mesotron should completely disappear, or if its mass should suddenly shrink to that of an electron, there would be an amount of energy to dispose of comparable with that which would be given to a single electron by one hundred million volts. What becomes of this energy? The quantum theory of atomic structure has something to say about this matter and the conclusion is to the effect that the mesotron disappears in such fashion that half of its energy goes into an ordinary electron, while the other half goes into that mysterious entity, the neutrino, which is a kind of atomic bank into which the physicist puts the superfluous energy of his particles when he cannot find anything for it to do and when, to have it do something would be embarrassing to the situations concerned.

The neutrino is like the accounting books of the war debt: you never expect to see it paid, but you satisfy your conscience and the consciences of the debtors by keeping it on the records.

Now in order to test this act of death of the mesotron, Dr. and Mrs. Montgomery, in conjunction with Mr. W. E. Ramsey and Mr. D. B. Cowie,[6] have designed an experiment. This experiment will be clear from Fig. 7, and from the following description. First, we have a piece of lead. From

FIG. 7.



The disintegration of a mesotron in the thin plate of lead between the two counter trays produces an electron (full line) which traverses the lower tray, and a neutrino (dotted line). The large lead block above the whole reduces the proportion of the soft component of the cosmic rays.

the known absorbability of mesotrons we know how many mesotrons will disappear in that piece of lead in an assigned time. Some of these disappear while yet in action, in the sense that they possess kinetic energy and the power to break up into ions the molecules by which they pass. However, it is possible to calculate, from the number entering the lead, the number which actually come to rest by frittering away their energy. Thus, in the particular piece of lead *A* used, which was 2 cm. thick, about 160 mesotrons would come to rest in

[6] C. G. Montgomery, W. E. Ramsey, D. B. Cowie, and D. D. Montgomery, *Phys. Rev.*, **56**, 635 (1939).

an hour. After coming to rest, a mesotron would live on the average about 2.5×10^{-6} second, and then, according to the views above cited, should shoot out an electron of about fifty million electron volts. Suppose now that a mesotron passes through a tray of Geiger counters, *B*, placed above the piece of lead and that the mesotron is destined to come to rest in the lead, and suppose that 2.5×10^{-6} second later it shoots out an electron which passes through a Geiger counter tray, *C*, placed below the lead. Suppose further that we arrange these two Geiger counter trays in relation to the electrical circuits associated with them so that they will only operate the final recording device provided that the lower one is delayed in action in relation to the upper one by 2.5×10^{-6} second. Under these conditions, we shall just succeed in recording that electron which was emitted when the mesotron died. If the time delay between the two counter trays is too little, we shall not record it. Of course, since the life of the mesotron only has significance as regards an average, there will not be one, and only one, time delay appropriate to the capture of all the emitted electrons.

In practice the apparatus was arranged so that there was a time delay which could be varied, and all electrons arriving at the second set of counters after an interval corresponding to that time delay were thus recorded. It will be seen that, provided that the process envisaged actually takes place, the method provides another means for measuring the mean life of the mesotron.

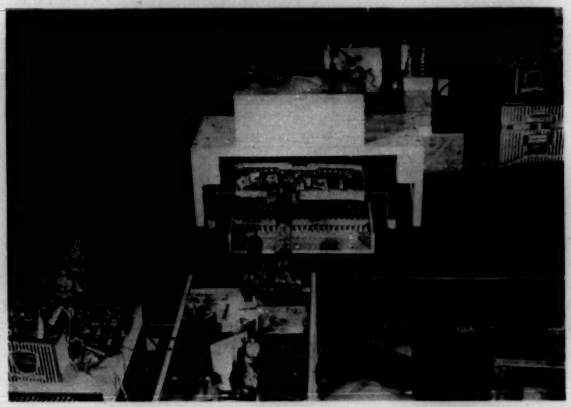
Now when the experiment was performed, it was found that the number of electrons recorded in the manner indicated was certainly no more than one-fifth of what it should have been on the basis of a mean life of the order of 2.5×10^{-6} second. The results indicate, therefore, either that the mean life in the resting state is much smaller than the value cited, or that the mesotrons die for the most part before they have reached zero velocity, by some process other than that discussed above.

The apparatus used in these experiments is shown in Fig. 8, and the details will be clear from the caption.

Production of Showers by Mesotrons.—Last year I described some experiments by Dr. and Mrs. Montgomery in which

they measured the number of large bursts of ionization which occurred in their apparatus in a given time in a mine 100 feet below sea-level. I have already reported that they found a situation in which, initially, the decrease in number of large showers with increase of depth was very rapid; but this very rapid decrease was followed at greater depths by a much more gradual decrease. The complete detailed investigation of this phenomenon is one which is still under way; but there is

FIG. 8.



Below the large block of lead in the center of the photograph are two trays of Geiger counters. The upper one records the presence of a slow mesotron and the lower, the disintegration electron produced when the mesotron dies after a short interval of time. In the foreground are the recording and calibrating vacuum tube circuits.

another aspect of the investigation which was not reported last year, which forms part of the story, and which will now be discussed.

If shower rays are allowed to fall upon a piece of lead of suitable thickness, they become enhanced in number on account of the multiplicative process; and it is of interest to study the relative characteristics of the rays from showers from different materials by measuring the factor by which the rays from these different showers become enhanced in passing through the lead.

As a corollary to their mine experiment, Dr. and Mrs. Montgomery measured this growth of showers in lead under a meter of earth,[7] and they subsequently repeated the experiment in the free air at sea-level. It was found that the nature of the phenomenon was different in the two cases. The proportional increase in the number of showers, as well as in the total number of rays in all showers, was greater for the showers from the air than for the showers under the meter of earth, which latter originate presumably in the material of the earth above. Since the enhancement of electrons by pair production in lead is greater the greater the energy of the entering electron originally responsible for the secondaries, we arrive at the important conclusion that the electrons from the air have, on the average, a greater energy than the electrons from the earth.

The interpretation which Dr. and Mrs. Montgomery place upon this phenomena is as follows: They assume that shower phenomena produced by mesotrons are of two types. First, we have the ejection of an electron from an atom by the mesotron with high speed, the electron being the agency ultimately responsible for the shower. In this act the mesotron loses only a portion of its energy. In the second method we have a complete disintegration of the mesotron into an electron and a neutrino.

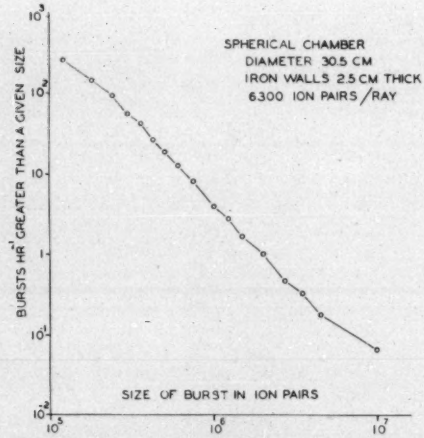
Now the chance of the mesotron ending its life and so of producing showers of the second kind in a given distance is the same whether that distance is traversed in air or in a dense medium. However, the chance of the shower of the first type being produced in the assigned distance is much greater for the dense medium than for the rare medium. Hence, we should expect that the showers of the first type would be much more prominent in relation to those of the second type in the case of the underground observations, where they come from the dense earth above, than in the case of the air. The results of the Montgomerys are, therefore, harmonized by the very natural assumption that the shower rays produced by meso-

[7] C. G. Montgomery and D. D. Montgomery, *Phys. Rev.*, **56**, 640 (1939); also, *Rev. Mod. Phys.*, July–October (1939). Some of the results obtained in these papers were obtained subsequent to the present report, and will be described in the Director's Report for next year.

tron disintegration are of greater energy than those produced by the other process and by the accompanying assumption, justified on the foregoing considerations, that it is the disintegration showers which are important in the air, while the other types of showers are important in the dense medium.

On the Continuity Between Large and Small Showers.—Much interest has centered round the form of the curve which one obtains when one plots the number of showers having a

FIG. 9.

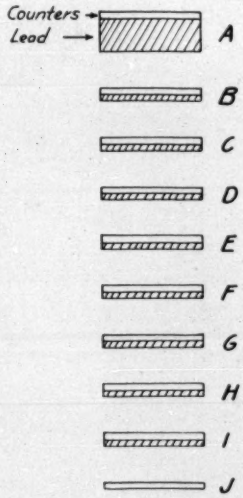

SPHERICAL CHAMBER
DIAMETER 30.5 CM
IRON WALLS 2.5 CM THICK
6300 ION PAIRS/RAY
BURSTS HR⁻¹ GREATER THAN A GIVEN SIZE
SIZE OF BURST IN ION PAIRS

size greater than a certain lower limit against that lower limit. It has been contended in the past, and still is contended by some, that this curve shows a maximum in the vicinity of showers representative of 200 rays. The doubts in this matter have arisen from the difficulties inherent in measuring showers of small sizes. With the perfection of technique which they have developed, Dr. and Mrs. Montgomery have succeeded in showing that there is no maximum at any rate down to showers as small in size as those composed of 16 rays. Moreover, in the opposite direction their observations, taken with the same apparatus, extend without maximum to 1600

rays, as shown by the curve in Fig. 9. These results obviously have a profound bearing upon the nature of the origin of these showers.

Other investigations in shower phenomena under way in the hands of Dr. and Mrs. Montgomery concern the dependence of shower production upon the nature of the element in which the showers are produced.

FIG. 10.

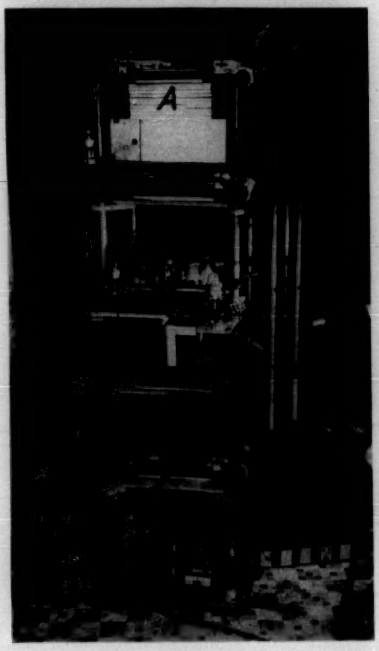


Further Investigation of Shower Phenomena Associated with Mesotrons.—Last year I described a proposed apparatus for the investigation of shower phenomena in detail, and more particularly for the investigation of showers produced by mesotrons. I repeat here the brief outline of the principle together with Fig. 10, from my last report.

The apparatus comprises the following parts: First, there are eight slabs of lead, shown cross-hatched, each 1 cm. thick. Above each slab, as shown in *B*, *C*, *D*, *E*, *F*, *G*, *H*, *I*, is an array of Geiger-Müller counters. Each counter is 20 cm.

long and 1 cm. in diameter. The counters are packed in trays, each tray forming a plane of counters with their axes parallel. Thus, a whole tray constitutes a square sensitive

FIG. 11.



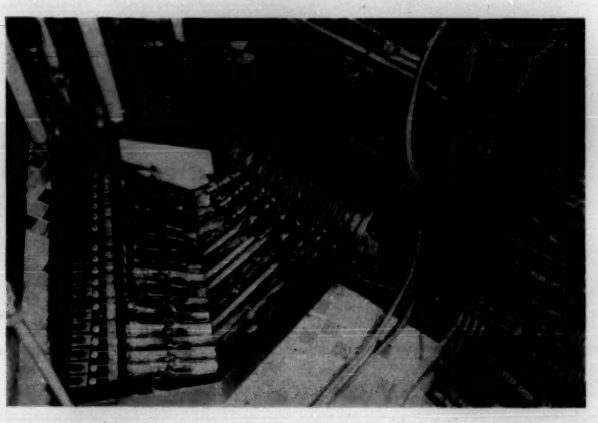
At the top of the column is the mass of lead, *A*, 18 cms. in thickness. Immediately above and below this mass of lead are two counter trays which are not very visible on account of foreshortening. To the right of each, however, will be seen the boxes, *B*, which contain the electroscope systems. Half way down the diagram is another counter tray which is quite visible, and below it in succession are three others, the directions of the counters in the successive trays being alternately perpendicular to one another.

area, 400 square centimeters in size. Above this assembly is placed a slab of lead 18 cm. thick, and on the top of this is placed an additional counter tray, *A*, similar to the others, and still another tray, *J*, is placed below all of the slabs of

lead, as shown in Fig. 10. Counting from the top downwards, the successive counter trays are arranged with their counters alternately in perpendicular directions.

Every counter is connected to an individual electroscope, so that in all there are 180 such electroscopes. Each electroscope carries a mirror, and by means of a suitably designed optical system, each mirror is caused to shine a spot of light

FIG. 12.



The horseshoe-shaped elements at the left indicate the positions of the electroscopes. The electroscopes are connected through rectifiers to their corresponding counters which, in the figure, are shown immediately to the right and above the center.

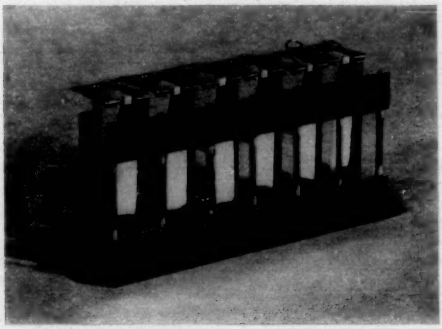
upon a ground glass screen, so that in principle we have ten parallel rows of spots. In practice, it was found convenient to have two ground glass screens, each caring for five rows of spots.

Now, the electrical circuits associated with the counters are so arranged that none of these electroscopes are permitted to operate unless at least one counter in each tray discharges simultaneously.[8] The control thus provided insures that any

[8] As a matter of fact, it is not necessary to cause all of the ten counter trays to participate in this control feature. It is sufficient to invoke the trays *A* and *J*, together with as many others as are sufficient to insure the desired degree of resolution against strays.

electroscope deflection recorded is associated directly or indirectly with a ray which has passed through all nine slabs of lead, and which may thus be regarded, in general, as a penetrating ray. However, when the simultaneous discharge of one or more counters in each tray permits the apparatus to operate, the deflections of the electroscope spots which result provide a complete record of all that has happened as regards shower production in the various slabs of lead initiated by the passage of the penetrating ray which was responsible for operating the "master control." [9] In this way, we have

FIG. 13.



a means of tracing the initiation and growth of a shower phenomenon in the ten pieces of lead and we have a guarantee that the said shower phenomenon must have originated from mesotrons, since only such rays—with very rare exceptions—could pass through 18 cms. of lead.

During the past year the apparatus has been constructed, and is shown in Figs. 11 and 12. Figure 13 is a picture of six of the electroscopes. A great deal of development has been necessary both in regard to the optical systems and the satisfactory operation of the counters, but the apparatus is now ready for observations.

[9] By the "master control" we mean the control provided by the feature that the electroscopes are only allowed to operate when at least one counter in each tray discharges.

Figure 14 shows four rows of 18 spots, corresponding to four counter trays. The order of the trays, from top to bottom, is *A*, *B*, *C*, *D*. The displacement of the two spots in *A* and *B* signifies that a ray has passed through the corresponding counters, and the two displaced spots in *C* signify that two secondary rays have arisen in the lead above *C*.

Before long, we hope to have a large number of photo-

FIG. 14.

graphs of this kind,[10] and from them we expect to learn much concerning the shower producing characteristics of the mesotrons.

NEUTRONS IN COSMIC RAYS.

It will be recalled that neutrons are neutral particles having a mass about 2000 times that of the electron. Since their discovery, they have played an increasingly important part in atomic phenomena and it has, therefore, always been a matter of conjecture and interest as to whether or not they play a part in cosmic-ray phenomena.

Neutrons are not easy to detect, either by ionization chambers or by Geiger counters, because they produce no direct ionization. They operate by knocking protons, alpha particles, or similar ionizing entities, out of atoms with velocities sufficient to cause these entities to ionize, and it is by this indirect effect that the neutrons are detected. Parafin and other hydrogen containing substances are good media for the purpose of providing protons when bombarded by neutrons.

[10] Important results obtained since the presentation of this report are described in the following publications: W. F. G. Swann and W. E. Ramsey, *Phys. Rev.*, **56**, 378 (1939); W. F. G. Swann, *Rev. Mod. Phys.*, July–October, (1939). These results will be described in the Director's Report for next year.

In the last National Geographic U. S. Army Air Corps stratosphere flight, Drs. G. L. Locher and L. H. Rumbaugh [11] of our laboratory sent up photographic films covered with parafin, the idea being that any neutrons in the cosmic rays would knock protons out of the parafin; these would enter the photographic emulsions of the films, producing tracks which could subsequently be detected with a microscope. The results of these experiments gave evidence that, in the stratosphere, the number of neutron rays was comparable with the number of ordinarily measured cosmic rays. However, since the neutrons have sensibly no effect in producing ionization, their actual contribution to ordinarily observable cosmic-ray phenomena is unimportant. Their main importance lies in the bearing of their presence upon the nature of the ordinary cosmic rays, after the manner of the principle that a man is known by the company he keeps.

With the foregoing estimate of the neutron intensity in the stratosphere, combined with our knowledge of the absorption of neutrons in air, we should be led to conclude that the number of neutrons at sea level would be immeasurably small were there none others than those which had succeeded in traveling from the stratosphere through the atmosphere. If, therefore, it should turn out that neutrons actually exist in measurable numbers at sea level, the fact would be of profound interest in connection with the story of the origin of secondary cosmic-ray particles and their associates in the atmosphere itself.

A German investigator, E. Fünfer, found at sea level a neutron intensity which, measured by the number of rays, was about one-twentieth as great as the cosmic-ray intensity. These results were received with some scepticism by the general cosmic-ray community. The scepticism was increased still further in the direction of doubts as to the meaning of the measurements when a paper by H. von Halban, Jr., L. Kowarski, and M. Magat in the *Comptes Rendus* claimed a measured neutron intensity more than twenty times that found by Fünfer.

Now during all of this period, and stimulated by the results of Drs. Locher and Rumbaugh, Dr. S. A. Korff had

[11] L. H. Rumbaugh and G. L. Locher, Nat. Geog. Soc. Contr. Tech. Papers, Stratosphere Series, No. 2, pp. 32–36, 1936.

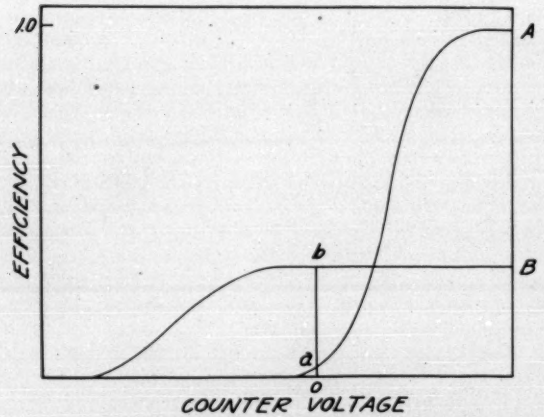
been developing Geiger counter methods for the measurement of cosmic-ray neutrons in radio-recording, unmanned balloon flights. Dr. and Mrs. Montgomery, working from another angle, had been developing methods for detecting neutrons by the ionization which they produce indirectly in a gas-filled chamber, as the result of heavy charged particles which they shoot out from the atoms of a suitably chosen gas. They finally realized a set of experiments, in which we have every reason to be confident, and which harmonize satisfactorily with the findings of Fünfer to the effect that the neutron intensity at sea-level is of the order of one-twentieth of the cosmic-ray intensity.[12]

It may be of interest to say a little concerning the technique of these experiments. Since a neutron does not ionize, it cannot discharge a Geiger counter in the ordinary way. If, however, the Geiger counter is filled with a gas in which the neutron can produce atomic disintegration, the particles emitted in the disintegration can ionize the gas and so operate the counter. By using a Geiger counter in the ordinary way, however, even with a gas of the kind cited, the device would be quite unable to distinguish between the neutrons and the ordinary cosmic-ray charged particles. Either kind of ray would operate a counter. The ordinary cosmic ray operates the counter by generating relatively few ions in it, and these, under the acceleration produced by the large field between cylinder and wire, promote in the counter, the disruptive discharge which is observed. The neutron, acting through the heavy charged particles which result from the disintegration of the gas, is responsible for a much larger initial spurt of ionization than would be produced by the cosmic ray. However, a counter operating on normal conditions of poten-

[12] It may be worth while to remark that neutrons are classified into fast neutrons and slow neutrons, the former having energies above something between ten thousand and a hundred thousand electron volts. In the slow neutron range, however, there is a very important group, called thermal neutrons, which are of energies extraordinarily small for free atomic entities. These neutrons, in fact, have energies comparable with only one-thirtieth of an electron volt. The experiments of the Montgomerys, and those of Fünfer, dealt with thermal neutrons, whereas those of Locher and Rumbaugh dealt with fast neutrons of energies sufficient to knock protons out of paraffin, and endow them with energies sufficient to produce copious ionization.

tial utilizes this initial spurt only as a trigger and cares not for its amount. To distinguish between neutrons and cosmic rays, we must seek some principle of operation which makes use of the difference between the initial spurts of ionization resulting from the two entities. This principle of operation is realized by lowering the potential of operation of the counter. As we lower that potential, we come to a stage where the counter will operate for large initial spurts but not

FIG. 15.



Curve *A* is the counter response to beta rays and curve *B* is the counter response to neutrons. When counter is operated at voltages somewhat below o, no beta rays whatever are counted, and all counts are due to neutrons producing alpha particles or high energy recoil particles in the counter.

for small ones. The discrimination between the two depends upon the pressure in the counter as well as upon the potential, and our neutron sleuths aforesaid have made a complete investigation of this matter. The results are perhaps best represented qualitatively by the curves in Fig. 15. *A* is supposed to represent the efficiency of the counter for electron rays as a function of the voltage. It attains a value unity for a certain voltage and below that voltage it drops off rapidly with further decrease of voltage. It may be supposed to

have been obtained by measuring the apparent cosmic-ray intensity as a function of the voltage. *B* is supposed to be a similar curve drawn for the neutrons. It may be supposed to have been obtained by superposing the beam of neutrons upon the cosmic rays and taking the difference between the curve so obtained and the curve *A*. The circumstances are such that even at high voltages *B* can never attain anything like 100 per cent. efficiency for a small counter. However, as we lower the voltage, the electron curve falls more rapidly than does the neutron curve, and we eventually reach a point where the latter lies above the former. In this region the power to discriminate between neutrons and cosmic rays is represented, for example, by the line *ab*. A good neutron discriminator is one for which the ratio *ob* to *oa* is as great as possible. For any given pressure of gas, we can assign a voltage for which this ratio is satisfactory. However, the ratio for any voltage depends upon the pressure, and by choosing the pressure properly it is possible to realize a condition which represents the maximum degree of discrimination. Thus, for example, with a counter 20 cm. long and 2 cm. in diameter, filled with boron trifluoride at a pressure of 11 cm., and operated at the voltage corresponding to *o*, Fig. 15, we have a ratio of *ob* to *oa* greater than ten.[13] By operating the counter at a voltage below *o*, no beta rays whatever are counted, and all the counts observed are due to neutrons.

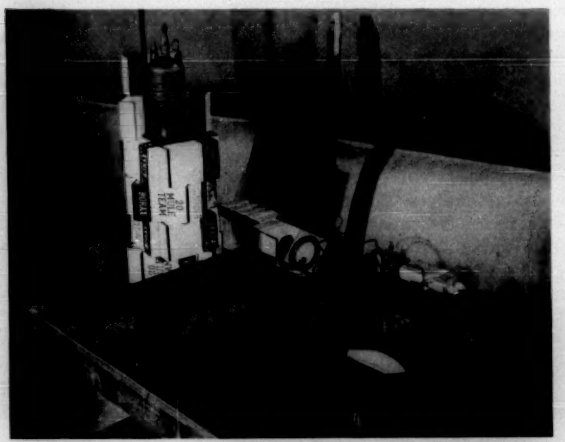
Now if the counter is made of large size and filled with gas at a pressure which is no longer as low as that ordinarily used in counters, and if the potential is lowered still further beyond the value which one would use for ordinary counter operation, the tube simply reverts to an ordinary ionization chamber in which the thing to be measured is the actual spurt of ions produced, but in which the actual efficiency of the tube for detecting neutrons has been greatly increased by

[13] At this point, an illustrative experiment was performed. The Geiger counter referred to in the text was operated at a potential of about 2,000 volts, the counter itself being surrounded by one centimeter thickness of paraffin to slow the neutrons down to an energy at which they become efficient for the operation of the counter. Under these conditions, the counter was shown to respond to beta rays as well as to neutrons. On lowering the potential by 200 volts, it ceased to respond to the beta rays, but continued to respond with practically unaltered efficiency to neutrons.

the larger pressure and gas path. This is the device which, in company with suitable amplifying apparatus, Fig. 16, has been used by Dr. and Mrs. Montgomery in the investigations above described.

As I have already stated, Dr. Korff is engaged upon high altitude flights with radio-recording, unmanned balloons, for the purpose of measuring, among other things, the variation

FIG. 16.



The cylindrical ionization chamber at the left, surrounded by boxes of borax for shielding out slow neutrons, contains boron trifluoride gas which is disintegrated by neutrons in the cosmic radiation. The products of the disintegrations are detected by the ionization which they produce, and the amount of this ionization is amplified and recorded photographically by a recorder not shown.

of neutron intensity with altitude. The principle of operation is in most respects similar to that which has been used by Dr. Korff on former flights concerned with the measurement of the cosmic-ray intensity with single counters, and by Dr. Johnson with triple coincidence counters. However, the single counter was arranged to record neutrons in the manner already described. At sea level the apparatus gave about 10 signals per hour and this changed in a flight more or less

continuously by a factor of 5 up to an altitude of 20,000 feet, when this particular series of observations terminated on account of radio interference which happened to occur from another transmitting station. This particular experiment was done before the perfection of discrimination between neutrons and other rays had been carried to the point to which it has now reached, so that the results are only to be regarded as of a preliminary nature. The path has now been cleared for obtaining results which are completely unambiguous in their interpretation, and Dr. Korff hopes to make some further flights in the immediate future.[14]

In concluding these remarks, which are concerned primarily with the existence of neutrons in the cosmic rays, it is perhaps worth pointing out that the development of these low potential neutron counters provides a useful tool for general investigations in nuclear physics, apart from cosmic rays, and particularly those concerned with very low neutron intensities.

COMPARISON OF GEIGER COUNTER DATA AND IONIZATION CHAMBER DATA FOR THE VARIATION OF INTENSITY WITH ALTITUDE.

In previous reports I have frequently had occasion to refer to the two different types of methods of measuring cosmic-ray intensity. First, we have the Geiger counter method, which counts individual rays and in which, by placing three Geiger counters in tandem, we can form the equivalent of a cosmic-ray telescope for measuring the intensity of the radiation in any direction.[15] This is the kind of apparatus which we used in the three manned balloon stratosphere flights in which the Bartol Research Foundation participated. It is the kind of

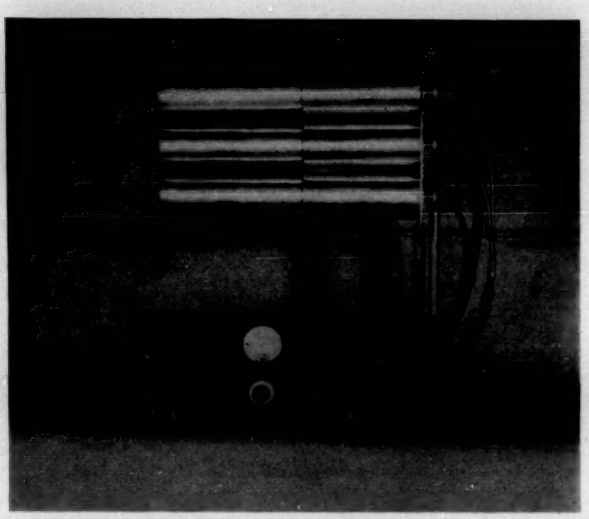
[14] Since this report was presented, important data up to altitudes of the order of 60,000 feet have been obtained. These results will be described in the next Director's Report. They have been published in full in *Reviews of Modern Physics* (S. A. Korff, *Rev. Mod. Phys.*, 11, 210 (1939).)

[15] The remarks at this stage were illustrated by the exhibition of a triple coincidence set designed by the Bartol Foundation for the realization of a feature in which it is intended to cause a cosmic ray to operate a relay which will turn on the lights at the opening of the New York World's Fair. The apparatus is shown in Fig. 17.

Note Added Feb. 15.—This apparatus, after performing its original duty of turning on the lights at the World's Fair, has been in continuous use at the Hayden Planetarium in New York.

apparatus which we have used in our airplane measurements and in the investigations carried out by Dr. Johnson and Dr. Korff in their radio-recording, unmanned balloon flights. The second method of measurement is by the utilization of an ionization chamber, in which the cosmic rays render the

FIG. 17.



The three gunlike units contain in their front ends the Geiger counters and in their rear ends part of the amplifying devices which are ultimately responsible for operating the recording mechanisms not shown in the figure. The dial panel below is for purposes of adjustment. The recording devices were associated with the system through which, by the passage of a cosmic ray through the three Geiger counters, the illumination at the World's Fair was turned on.

air within the chamber conducting, so that by means of an electrical potential difference between the wall of the chamber and a central insulating rod a current of electricity flows to the central rod and through a suitable recording device becomes a measure of the intensity of the radiation.[16] This was the principle used in nearly all early investigations, and

[16] Here was shown an experiment in which the cosmic-ray current from an ionization chamber was caused to register upon a quadrant electrometer.

is the principle which has been used by Professor R. A. Millikan, his collaborators, and others, in measuring the variation of intensity with altitude in manned and unmanned balloons. Instead of measuring the intensity in a single direction it gives a value in which all directions participate.

Now the problem of the harmonization of the results given by Geiger counters and ionization chambers has been for long one with no very complete and satisfactory solution. This arose possibly from the scarcity of Geiger counter data of sufficient accuracy to warrant careful comparison with the ionization chamber data, and in part from the uncertainty of the effects to be expected as a result of the influence of the walls of the ionization chamber upon the phenomena.

In 1937 Dr. Danforth and I extended the results obtained with our large Geiger counter apparatus used in the stratosphere flight to lower altitudes by means of airplane flights and obtained data which we feel to be of considerable accuracy, so that a comparison with the ionization chamber data attained a renewed interest.[17] The advance of our knowledge of the consequences of shower production in such material as composes the walls of the vessel has brought us to a stage where we can talk with some greater confidence than was possible even two years ago with regard to the question as to what it is reasonable and what it is not reasonable to suppose to be happening in such walls, and so within the last year, Dr. Danforth and I have utilized our Geiger counter data in combination with those of other observers who used ionization chambers for the purpose of seeking a more clear understanding of what is involved in the relationship between the two.

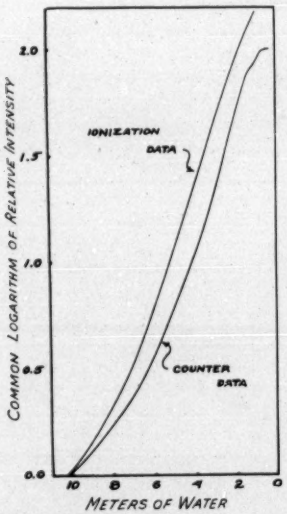
Since, in our counter measurements in airplane and in balloon, we measured the intensity at different zenith angles from vertical to horizontal, it was possible to deduce from our observations what the relative ionization in an ionization chamber should be at various altitudes on the assumption that all of the rays measured by our counters ionize to the same extent per unit of path at all altitudes.[18] In Fig. 18

[17] W. F. G. Swann and W. E. Danforth, JOUR. FRANK. INST., 228, 43 (1939).

[18] The *relative* ionizations in the chamber at different altitudes are not affected by secondary rays from the walls to the extent that such rays traverse the whole vessel and exist in the same proportion in relation to their primaries at all altitudes.

the curve marked "counter data" gives the logarithm of the ratio of the ionization as calculated in this way to the corresponding ionization calculated for sea level. The curve marked "ionization data" represents similar quantities taken from the actual ionizations measured with Professor Millikan's apparatus in the Settle-Fordney flight. It will be observed

FIG. 18.



that the curves diverge even at relatively low altitudes, but attain finally an approximate parallelism until one reaches those higher altitudes at which the curves show the influence of the maximum resulting from the limitations of the atmosphere.

Now if, in line with modern ideas in cosmic radiation, we suppose that the rays are of two types, electrons and mesotrons, we can obtain an explanation of the difference between the two curves in Fig. 18 by assigning different ionizations per

centimeter of path to the electrons and the mesotrons, representing all effects from the walls of the vessel in each case by a factor β for the mesotrons and $\epsilon\beta$ for the electrons, these factors being the quantities by which one must multiply the normal ionization per unit of path by an electron in order to obtain results which harmonize with the experimental data.

Electrons accompany the mesotrons even at low altitudes, and these electrons have their origin from showers produced by the mesotrons. At higher altitudes, however, we have the additional electrons associated with the soft component, so that as we ascend, the correcting factor $\beta\epsilon$ appropriate to these electron rays becomes more and more representative and finally almost completely representative of the story of all the rays. Herein lies the story of the divergence of the two curves in Fig. 18 and of their ultimate approach to parallelism.

In addition to these considerations, which involve only the ratios of ionizations at different altitudes to that at sea level, we have the necessity of harmonizing the actual measured ionization in a closed vessel at sea level with that to be expected when properly calculated from the numbers of rays as given by Geiger counters. The disentanglement of the various elements involved is a little complicated, but certain consequences emerge unambiguously.

In the first place, even if there were no separation between the curves of Fig. 18, the harmonization of the sea level data necessitates a value of β given by

$$\beta = 3\,\frac{(1+\alpha)}{\alpha}, \qquad (1)$$

where α is the ratio for sea level, of the total number of mesotrons entering the ionization chamber to the total number of electrons entering.[19] The experimental data in respect of

[19] The number 3 is the numerical representative of the expression $N_{i0}/V\rho J_0$ where N_{i0}/V is the ionization per cc. per second, given by R. A. Millikan as 2.48, where ρ is the normal ionization, 33 ions per centimeter of path at atmospheric pressure, for an electron as obtained by W. E. Ramsey and the writer, and J_0 is the integrated value of the intensity (as measured by numbers of rays) for all zenith angles, a quantity obtained by J. C. Street and R. H. Woodward as 0.025.

the proper value of α are rather meagre; but we see that even if the curves of Fig. 18 should coincide, we should still have β as large as 3.

The next matter of importance concerns the fact that we find

$$\epsilon = L\alpha/(1 + \alpha - L), \tag{2}$$

where L is the limiting ratio of the ionization in the vessel corresponding to the two curves in Fig. 18, and corresponding, moreover, to the region of parallelism. A limiting constancy of ratio is, of course, the equivalent of a limiting constancy in the difference of the logarithms, from which we can readily see that, regardless of the value of α, we can never have ϵ less than L. Only when the two curves of Fig. 18 coincide so that $L = 1$ can we have ϵ as low as unity. In other words, the fact that the experimentally measured ionization curve falls above the curve calculated from the counter data necessitates that the electron rays must be assumed to ionize, either directly or through their secondaries, to a net extent which is greater than that for the mesotrons.

The quantity $\epsilon\beta$ representative of the correcting factor for the electrons is given by [20]

$$\epsilon\beta = 3L, \tag{3}$$

regardless of the value of α. And, with the value $L = 2$ appropriate to Fig. 18 we find $\epsilon\beta = 6$. From this value, there is no escape by the adjustment of α. The correcting factor for the soft component is fixed entirely by L. However, the quantity β, which is given by

$$\beta = 3\,\frac{(1 + \alpha - L)}{\alpha}; \tag{4}$$

is dependent upon α. If, with $L = 2$, we seek to make β equal to unity, which would be the most satisfactory conclusion consistent with the mesotron nature of the rays, we should require $\alpha = 3/2$. However, such data as exist seem to suggest that α must be greater than this and that it may

[20] The 3 is a numerical representative of $N_{i0}/\rho V J_0$.

be as high as 3. This value, with $L = 2$, would require $\beta = 2$.[21]

However, while there may be some uncertainties in the correcting factor β for the mesotrons, the correcting factor $\beta\epsilon$ for the electrons is much less ambiguous and has the value 6. This value is very much larger than can be harmonized with the ordinary theories of shower production in the walls of the vessel and points to some additional circumstances which it remains for further study to reveal.

The Significance of the Variation of Cosmic Radiation with Zenith Angle.—Our high altitude work has served to enhance again a point which I think has not been sufficiently recognized, and which was brought out in the three manned balloon stratosphere flights in which we participated. This point has to do with the variation of cosmic-ray intensity with zenith angle.

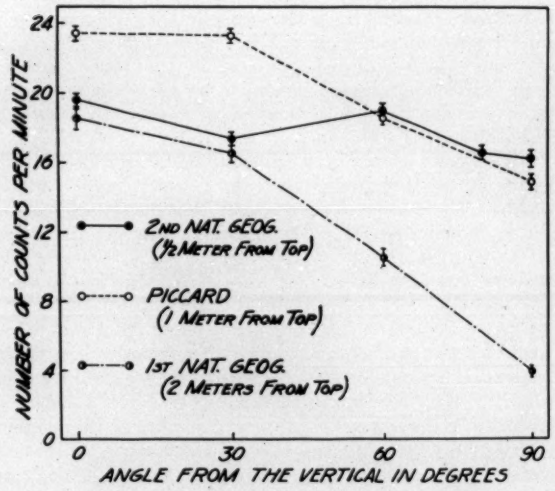
It has been customary to assume that[22] the cosmic-ray intensity in any direction defined by a zenith angle θ in the atmosphere is the same as the vertical intensity at some lower depth so chosen that the equivalent air paths are the same. This assumption implies that even at high altitudes the cosmic-ray intensity falls to sensibly zero value in the horizontal direction. Thus, for example, at an equivalent depth of 0.5 meter of water equivalent atmosphere the air path, at an angle α from the horizontal such that $\cos \alpha = 0.1$, is the equivalent of 10 meters of water, so that, according to the view stated, the intensity in this direction should be smaller than that in the vertical direction in the ratio of the vertical intensity at 0.5 meter to the vertical intensity at a vertical depth of 5 meters of water equivalent. On this basis, the intensity in the direction concerned should amount to only

[21] *Note added Dec. 15, 1939.* Recent observations by R. B. Brode (*Rev. Mod. Phys.*, 11, 222 (1939)) suggest that the specific ionization ρ appropriate to the energies here concerned should be about twice the value 33 ions per cm. cited in the text. If we accept this conclusion, the 3 of equation (3) would be replaced by 3/2, and the conclusion would be $\epsilon\beta = 3$. Again, with $\alpha = 3$ and $L = 2$, and with the above modification, equation (4) would lead to $\beta = 1$, which is very satisfactory from a theoretical standpoint.

[22] Apart from slight corrections arising from geomagnetic effects and from corrections concerned with the mean life of the mesotron, which are unimportant in connection with the considerations now under discussion.

about 17 per cent. of the corresponding vertical intensity. Figure 19 shows our results obtained for the variation of intensity with zenith angle in the two National Geographic U. S. Army Air Corps stratosphere flights and in the Jean Piccard flight. At a water equivalent depth of 0.5 meter, the intensity as measured by our horizontal telescopes was only 20 per cent. less than that for the vertical direction. At 1 meter depth the horizontal intensity amounted to 50 per cent.

FIG. 19.



of the vertical, and at 2 meters water equivalent depth it amounted to 20 per cent. of the vertical.

It is true that our counters subtended a fairly large angle, so that they do not measure the intensity in a single direction. The counter areas were squares 3 cms. in side, the outer members of the triple coincidence set being 9 cms. apart, so that there is an uncertainty in the angle of the order of one-third of a radian. However, it turns out that even in the case which is worst from the standpoint of this uncertainty,

the case where no rays have an *upward* component of velocity, our telescope with horizontal axis would measure the intensity at an angle of no more than one-ninth of a radian from the horizontal.[23] Thus, in line with the foregoing considerations, if the telescope at a water equivalent depth of 0.5 meter measured an intensity only 20 per cent. less than that for the vertical, then if the intensity depended only upon the equivalent path length from the top of the atmosphere, we should find, at a depth of 9×0.5 (= 4.5 meters) water equivalent, a vertical intensity only 20 per cent. less than the vertical intensity at a depth 0.5 meter, a conclusion entirely inconsistent with the facts. We are forced, therefore, to conclude that our observations deny the equivalent path hypothesis for high altitudes.

The fact that the intensity varies with zenith angle in the manner which I have indicated at high altitudes results in a serious defect in the customary method of reducing ionization chamber measurements to an apparent equivalent in terms of vertical intensity, a method which continues, however, to be used.

When we first observed the strong horizontal intensity at high altitudes, I attributed it, in part at any rate, to the bending of secondary electrons by the earth's magnetic field. The growth of our knowledge of pair production and of the formation of secondaries in the atmosphere enhances the certainty with which we may talk in terms of this phenomenon.

I have had frequent occasion in these reports to discuss the effect of the earth's magnetic field in bending the paths of charged particles which come to us from outer space. In general, an electron, for example, must possess considerable energy in order to penetrate the earth's magnetic field, an energy of about 6 billion electron volts for a vertical entry at a magnetic latitude of 42°. Such electrons would have their paths bent very little in traveling many miles. However, on striking the atmosphere, they give rise to secondary electrons of lower energy which are bent more easily. These give rise to further progeny of still lower energy, and these

[23] We take into account the fact that on account of the angular spread of the telescope, it receives rays at both ends.

are bent more easily still. Superposed upon all of this, we have the energy lost by ionization as these secondary particles pursue their paths, and this tends also to accelerate the bending as the energy diminishes.

The quantum theory enables us to trace the history of this story, and I have succeeded in tracing the history in some detail. However, interesting as this problem is on its own merits, it cannot form the complete solution of the large cosmic-ray intensities at large zenith angles. For while such bending as I have referred to would tend to enhance the spreading of the intensity in the direction of large zenith angles in the equatorial plane, it would have a corresponding effect only to a diminishing extent in other planes until the effect vanished in the north-south direction. We should thus expect a greater intensity in the east or the west direction than in the north or the south direction at the equator. Now our data obtained on the last National Geographic U. S. Army Air Corps stratosphere flight gave, at the maximum altitude, a remarkable symmetry with azimuth. The intensity in the east differed from that in the west by less than 1 per cent., and they both differed from the average for all azimuths by less than 1 per cent. In latitudes comparable with 50°, the lines of force are more nearly vertical than horizontal, so that the effects are more complicated at these latitudes. However, Dr. Johnson's recent measurements at low latitudes give no evidence of a pronounced variation of intensity at large zenith angles with azimuth.

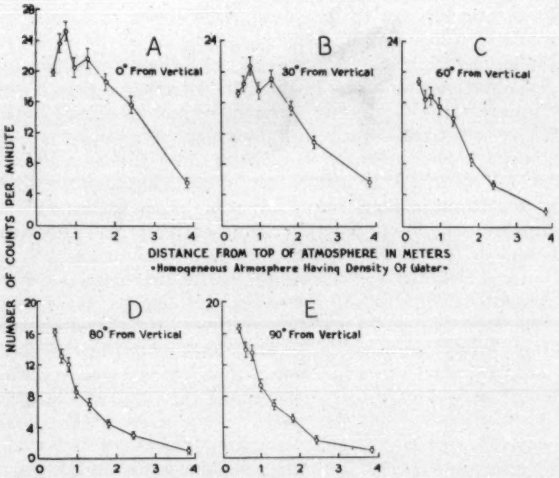
For the foregoing reasons, I think that we must look for some effect other than the magnetic bending for the explanation of the large intensity at large zenith angles. The facts could be accounted for if we should assume that there was a component of the incoming radiation which became absorbed in the higher regions of the atmosphere and produced, after a certain time delay, secondary bursts of radiation which were symmetrical in all directions. Theoretical considerations prevent its being a matter of great ease to realize a condition in which secondary bursts of rays occur in which the rays travel out from a center more or less symmetrically in all directions. The laws of conservation of energy and momentum conspire to insure in the secondary particles a

strong perpetuation of the direction of propagation of the primary particles. However, there are special cases in which we can side step this difficulty. In a paper presented at the Chicago symposium on Cosmic Rays last summer, I proposed a theory to which further reference will be made later in this report, and according to which cosmic-ray phenomena originate from a single primary component which gives rise, in the atmosphere, to electrons, either directly or through the intermediary of mesotrons. From other considerations, Dr. Johnson, in a paper to be summarized below, has also suggested a mesotron origin of this kind. Some of the mesotrons will disintegrate in the upper regions of the atmosphere. If we take our stand on one of these mesotrons, so that it is at rest in our frame of reference, we may expect its disintegration particles to travel out symmetrically. If, however, the mesotron moves with high velocity in our frame of reference, there will no longer be symmetry of emission, but unidirectional emission in that frame. If some of the mesotrons are created at rest in the earth's frame of reference, these can disintegrate, ejecting electrons traveling symmetrically in all directions. Moreover, according to the principles we have discussed above, it is the low energy mesotrons which have the greatest chance of disintegrating. If, therefore, the greater proportion of the mesotrons are created in the upper regions of the atmosphere, then in that region we may anticipate an approximation to symmetry of the ultimate electrons in all directions.

By such a process as that visualized, moreover, I think we can understand a certain phenomenon shown by the data from the second National Geographic U. S. Army Air Corps stratosphere flight which has always intrigued me, but which seems to have been overlooked in discussions of cosmic-ray phenomena. I refer to the double peak in the altitude intensity curves taken at different zenith angles and shown in Fig. 20. If one had this double peak in only one set of observations taken with a single counter telescope, one might be suspicious of its validity. The double peak is shown at the zenith angles other than the vertical, however, and the peak gradually dies out, as it should do, as the zenith angle is increased. The fact that the data for different zenith angles

were taken with *different* counter telescopes lends strong support to the reality of the phenomenon. The single peak is suggestive of a single phenomenon in which a primary entity enters the atmosphere and produces secondaries which first increase in number and then decrease as we descend. A double peak is suggestive of the kind of double process above referred to, a process in which the mesotrons are pro-

FIG. 20.



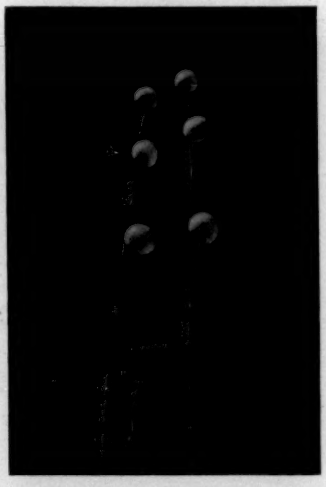
duced from the primaries and the electrons are produced from the mesotrons.

Returning to the question of the magnetic deflection of the secondary electrons, in spite of the fact that the magnetic effect in question would seem incapable of providing the complete story of the variation of intensity with zenith angle, the reality of its existence is not, therefore, in question; for its action is always in the direction of spreading the intensity over large zenith angles; and if there is some other agency which has a greater effect in this matter, that simply means

that the magnetic effect is unable to show itself as a separate influence.

High Altitude Measurements at Low Latitudes.—Dr. T. H. Johnson and Dr. J. G. Barry have recently continued their high altitude, radio-recording, unmanned balloon flights at Panama with the primary object of determining the relation between the east and west intensities of the radiation. It will

FIG. 21.



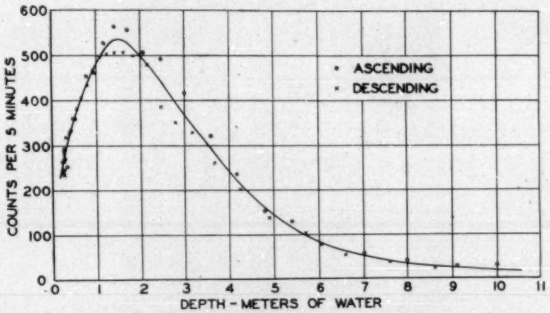
The balloons are shown at the top of the picture. Below the balloons is indicated, at *C*, the device for securing rotation of the apparatus during the ascent. The apparatus itself is shown at *A*.

be recalled that such a difference leads to conclusions as to the preponderance of one sign of charged particles over those of the other sign. Dr. Johnson and Dr. Barry found a slight asymmetry of the order of 7 per cent. at the zenith angle 60°, the greater intensity being from the west. In comparing this with the relatively large variation of intensity with latitude at the same elevation, Dr. Johnson comes to the conclusion that only a small fraction, of the order of one-tenth of the

total field-sensitive radiation, can be produced by unbalanced positive primary rays. Since the analysis of the latitude and directional effects at sea level shows that practically 100 per cent. of the field-sensitive mesotron component is produced by positive primary rays, he concludes that the mesotrons are not secondary to the primary electrons of the soft component, as is often supposed.

Figure 21 is a portion of Dr. Johnson's and Dr. Barry's apparatus in the process of a flight at Panama. Figure 22 shows the results of a flight in which the vertical intensity was the quantity measured. The results are of special

FIG. 22.



interest in that they extend to a very high altitude, and reveal a portion of the curve well past the maximum. It is a matter of profound importance to determine as exactly as possible the point at which this curve cuts the vertical axis, for that point determines the intensity of the primary rays. As will be seen, the nature of the curve is such as to leave considerable uncertainty on this point, and tends to emphasize the importance of further data at this high altitude.

It is of interest to remark that the ratio of the maximum intensity to the sea level intensity is 25, which is much smaller than the value—about 50—for higher latitudes, as it should be in the light of our general knowledge of the considerations which control the phenomena.

As the result of various considerations in which the asymmetry effects at high altitudes and at sea level play an important part, Dr. Johnson comes to the tentative conclusion that the primary radiation is composed of two parts, a proton radiation representative of the primaries of the hard component, and an electron radiation comprising electrons of both signs in sensibly equal numbers and constituting the primaries of the soft component. In this way one provides for an absence of asymmetry for the electrons which are dominant at the top of the atmosphere, but for an asymmetry for the hard component, which is determined primarily by the protons. In harmony with views expressed above, Dr. Johnson further arrives at the tentative conclusion that the protons produce mesotrons on their journey through the atmosphere, which mesotrons of both signs reflect, of course, the directional characteristics of their parent protons.

CERTAIN CONSIDERATIONS ON THE ORIGIN OF COSMIC-RAY PHENOMENA.

As I have remarked in several former reports, and in line with the discussion immediately preceding, it has been customary to regard the so-called soft and hard components of the cosmic radiation as initiated by two more or less independent primary agencies entering the atmosphere, an agency of electron type, and an agency representative of some different kind of particle of heavier mass, a proton, for example. The primary electrons are supposed to disappear very rapidly by pair formation in the upper regions of the atmosphere and to be represented by their progeny as the soft component in the greater part of the observable region of the atmosphere.

I have always felt that there would be something to be said for extracting the phenomena of both the hard and soft components from one primary agency entering the atmosphere; and last summer, as a contribution to the Cosmic-Ray Symposium at the University of Chicago, I developed a theory of the matter to this end.[24] The details are not suitable for presentation in an address of this kind, but the essential assumptions are as follows:

[24] W. F. G. Swann, JOUR. FRANK. INST., **226**, 757 (1938).

1. Each primary ray experiences per unit of water equivalent path a number of events, or collisions, this number, β, being independent of the energy of the ray, the events being distributed at random.

2. In each of these events, the ray loses an amount of energy, ϵ, which is the same for all energies.

3. If a ray has energy less than ϵ, it has nevertheless the same chance of experiencing an event; but in such an event it loses all of its energy.

4. When a primary ray loses energy, the energy loss goes into secondaries—possibly, in part, mesotrons—and some of it gets converted directly or indirectly into ordinary electrons which then proceed according to the pair production theory, the energy being lost, finally, by ionization in all cases.

If the energy loss per event were very small and the number of the events per unit of path were large, we should encounter a situation representative of that where the primary rays lose energy entirely by ionization. For any given entering energy there would be a definite path in the atmosphere, and all rays having that energy would travel one, and only one, distance. Penetration to different depths in the atmosphere would depend upon the energy distribution in the incoming radiation.

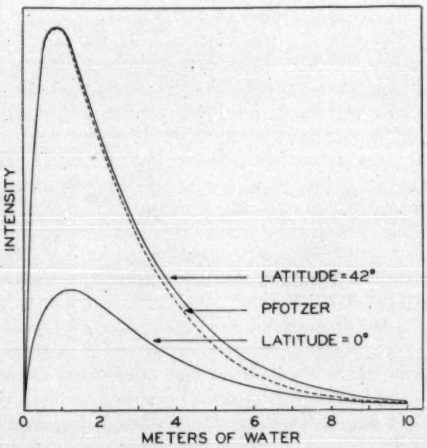
When the energy loss at an event is large and relatively infrequent, the statistical considerations demand that all rays, even of a single energy, do not travel one, and only one, distance. The fraction of the rays of a single energy which succeed in penetrating to a depth x, decreases with increase of x, but at a diminishing rate, so that at great depths the number of rays remains sensibly independent of the depth until the rays have traveled so far that all of their energy is lost. At these greater depths the behavior of the rays becomes characteristic of a range phenomenon and the variation of primary intensity with depth in these regions becomes determined entirely by the energy distribution in the incoming radiation.

Now when we superpose upon this the fact that the energy losses arise from the creation of electrons which subsequently produce other electrons by pair formation, the energy being continually dissipated by ionization, we arrive at a

situation in which, as we descend, the secondary intensity first increases as a result of the increasing amount of air above which is available for the contribution of the secondaries. Soon, however, a point is reached at which the gain from this cause is balanced by a loss resulting from ionization, and a maximum of the intensity is reached after which there is a decline in intensity with further increase in depth.

The characteristic features of this intensity altitude curve depend upon the quantity ϵ characteristic of the energy loss

FIG. 23.



per event, and the quantity β determined by the frequency of occurrence of the events.

If we assume $\beta = 4$, which corresponds to 4 events per meter of water equivalent, and if the loss of energy per event is 6×10^9 e.v., we find—for the secondary intensity—which on this theory represents practically all the measured intensity, the curve represented in Fig. 23. The curves are drawn for two latitudes, and the dotted curve represents the experimental measurements of G. Pfotzer, which measurements are in good agreement with our own.

The theory accounts for a number of significant experimental facts. Among these are the increase of latitude effect with altitude, and the increase of the average energy of the rays with depth for great depths of penetration in the atmosphere and in the substance of the earth, a fact discovered by Dr. and Mrs. Montgomery.

It is not maintained that the theory tells the complete story of all cosmic-ray phenomena in the atmosphere in all its details. However, it is possible readily to enrich it to include the phenomena, to which I have already referred, having to do with the double peak, and the uniformity of intensity in all directions in the stratosphere.

INVESTIGATIONS CONCERNING GEIGER COUNTERS.

Dr. G. L. Locher has continued his investigations upon the characteristics of Geiger counters, which play such an important part in our work.

Investigation of Gas Constitutions Suitable for Use in Geiger-Müller Counters.—A long series of investigations of the characteristics of counters filled with different gases and gas mixtures has been carried out. It is, of course, well known that the threshold voltage of a counter, and its efficiency for detecting radiation passing through the tube, depend upon the gas constitution. Likewise, the "plateau" or practical operating range of the tube depends upon the gas used. The wide range of possible combinations of gases, and the absence of any theory of the actual discharge mechanism of a counting tube leaves only the experimental method of attacking this problem. It may here be remarked that, despite the enormous amount of work that has been done on gas discharges, there is not very much that is applicable to the analysis of counter discharges. Substantially all of the precise gas-discharge experiments have been done with voltages and gas pressures that are not convenient for use in counters. There is at least one good reason for this: at the voltages and gas pressures used in normal counters, the discharge is of a *regional* nature, that is, it does not fill the entire tube. Analysis of such discharges would naturally involve considerations of the propagation of the discharge, the question of the size of the discharging volume, and especially, the question of the

reproducibility of the discharge. The fact that the discharges of a good counter are capable of reproduction to a high degree of accuracy is a fortunate fact, both from the standpoint of making reliable tubes, and for the possible ultimate evolvement of a correct theory of the discharge.

In the course of the investigations Dr. Locher has carried out this year, the characteristics of various tubes filled with helium, hydrogen, argon, neon, and air, and with these gases mixed in various proportions, and of tubes filled with these gases diluted with some vapors, have been examined. Some time ago, he carried out some experiments with similar counters, wherein binary mixtures of the above gases and nitrogen, with some vapors were used. In both series, the vapors included carbon-tetrachloride, nitric oxide (gas), carbon monoxide (gas), methane (gas), acetylene (gas), anisole and related compounds, benzene, and dichlorodifluoromethane. Many of the mixtures tried were successful, but without special merit, as compared with the argon-oxygen mixture that he devised in 1933 (94 per cent. argon and 6 per cent. oxygen). Generally, the function of the vapor (that is, of those successfully used) was to provide an attaching agent for otherwise free electrons in the discharge. For example, the most minute trace of dichlorodifluoromethane in a noble gas seems to suffice for this purpose; larger amounts of the vapor lead to very high (relative) starting potentials, accompanied by suppression of the current delivered by the tube, during discharge.

Low-voltage Counters.—Simultaneously with the above experiments, the matter of the size of the wire used (and to some extent the size of the cylinder) was also examined. Experiments done in this laboratory by C. L. Haines several years ago showed that the starting potential of a counter filled with any "ordinary" gas content, was higher for large wires than for small ones—as one would expect. But he also found that, at low pressures, the reverse was true, for unknown reasons. This suggested to Dr. Locher the possibility of making low-voltage counters—which are specially useful in work where battery weight is a matter of concern—by the use of large wires (rods) and low pressures of suitable gases or gas mixtures. The present experiments showed that this was not

practical. Instead, it is more desirable to use small wires and relatively high gas pressures. Moreover, it was found that mixtures of hydrogen with noble gases, as discovered by Max Cosyns, and of similar three-component mixtures, served best. An example of the latter is: 64 per cent. hydrogen, 32 per cent. neon, and 4 per cent. air.

The lowest practical voltage at which counters of the type were made to operate was about 400 volts. Generally speaking, the practical difficulties in making reliable tubes are much greater with low-voltage tubes than with higher-voltage ones. This fact was especially evident when the large wire and low gas pressures were used. However, there did not appear any reason for changing the mechanical form of the counter for low-voltage operation from that which Dr. Locher had developed, with the aid of Mr. Nester, for the first stratosphere flight (1933). Neither did there appear to be any reason for changing the cleaning and treating processes from those developed at the same time.

MISCELLANEOUS APPLIANCES.

As I have remarked in former reports, there emerge occasionally from our investigations side products which have use in fields other than in the main investigations themselves.

A New Portable Geiger Counter Apparatus.—As a result of some of the experiments described above, a new portable counter apparatus was made possible. This apparatus, designed by Dr. Locher, uses a low-voltage counter tube, or several thereof, and a light-weight amplifier and voltage supply, operated from low-voltage batteries. The high-voltage supply for the counter is obtained by the use of interrupted D.C. and a rectifier, both supplied by dry cells of ordinary types. The development of the electric circuit required considerable work, especially since the decline of potential of any dry cell with use and with age is fairly rapid. The counter tubes used have a voltage "plateau" of about 50 per cent. of their starting potential. The entire apparatus, with sufficient battery for about 24 hours of operation weighs 10.5 lbs. With batteries of 4 times that life, the weight is about 13 lbs. The apparatus provides a very quick and

effective means of locating lost radioactive material, and detecting small amounts of gamma-radiation.

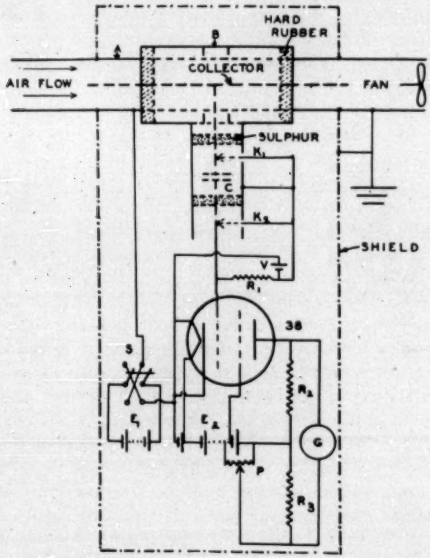
Sub-Threshold Operation of Counters.—During the summer of 1938, Dr. Locher developed a sensitive direct-coupled current-amplifier. This amplifier is linear for a change of input voltage of 0.5 volt, and serves as a good instrument for the investigation of counter operation in the vicinity of the threshold of the tube. The threshold voltage of a counter, or "starting potential," is a relatively definite point, ordinarily definable to at least 1 per cent. However, the use of any sensitive amplifier shows that this point is not entirely sharp, although it represents the initiation of a new class of cumulative ionization in the discharge. With the amplifier mentioned above, it was possible to operate ordinary counter tubes as much as 40 to 75 volts below the normal starting potential. In this manner, one can distinguish particles of different specific ionizations by the amplitudes of the current outputs of the pulses from this amplifier. When operated with gamma rays and cosmic rays, the counters show a range of pulse sizes, for a given sub-threshold voltage, due to different path lengths in the region of ionization in the cylinder, so it is not readily possible to measure the relative ionizations of particles of similar ionizing powers, with an arrangement of that type; but this does not prevent distinguishing between low- ionizing and high-ionizing particles. Counters thus used are similar in performance to the Geiger-Klemperer proportional counters, although their form is that of the Geiger-Müller counter.

An Apparatus for Recording the Electrical Conductivity of the Atmosphere.—The atmosphere, under normal conditions, is a conductor of electricity and while, to quote an illustration which I have cited on former occasions, it offers as much resistance to the flow of electric current as would a copper cable extending from here to the star Arcturus and back, many times over, so precise is our knowledge of the mechanism by which conductivity makes its appearance in a gas that the magnitude and variation of this conductivity becomes a matter of profound interest in atmospheric electricity. Moreover, so delicate are modern electrical instruments of measurement that we have but little difficulty in measuring it.

Of course, the conductivity of the air is caused by the

presence in it of positive and negative ions and the amount of the atmospheric ionization, particularly when enhanced by

FIG. 24.



Air is drawn by a fan through a grounded brass cylinder, A, surrounded by an insulated brass cylinder, B, which supports, through sulphur plugs, the ion collecting rod. This rod is coupled through the condenser, C, to the grid of the electrometer tube, type 38, keys K_1 and K_2 being normally open. Closing K_1 results in a ballistic throw of galvanometer G which is proportional to the quantity of charge collected. Since the time constant of the collecting system is large, we may integrate over quite long periods (when there are very few ions). When the number of ions is large, K_1 and K_2 are left open and S gives a steady deflection which is proportional to the ion current in A. Using the two procedures, and varying R_1, ion density varying from fifty to ten million ions per cubic centimeter can be measured. The reversing switch S makes it possible to gather ions of either sign.

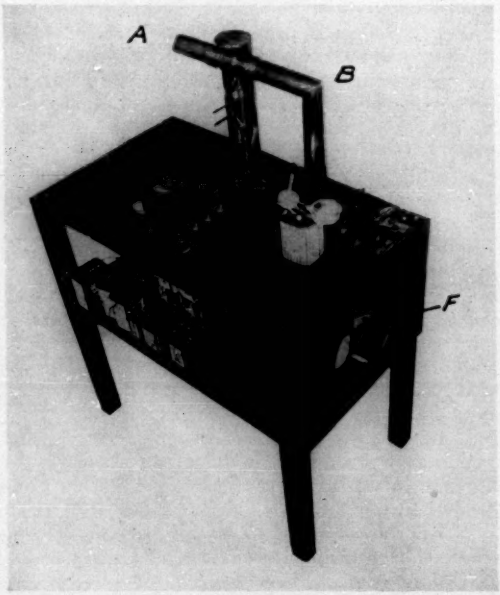
All stray electric fields, which otherwise would sweep ions from the vicinity, are eliminated by shielding.

R_1 = 10,000 megohms or less
R_2 and R_3 = 10,000 ohms
P = 400 ohms
E_1 = 200 volts
E_2 = 22.5 volts
V = 1.5 volts.

artificial production of ions, is becoming of more and more interest to those concerned with air-conditioning.

The normal method of measuring the electrical conductivity of the atmosphere is to blow a stream of air between two concentric cylinders, the central member of which is charged, insulated, and connected to an electrometer. The

FIG. 25.



Air enters the apparatus at *A*. The portion *AB* contains the electrode which collects the ions and which is connected to the vacuum tube system contained in the central vertical column. *F* is the fan which sucks the air through the apparatus. The remaining appliances are batteries and meters associated with the operation and measurements.

rate of disappearance of the charge in conjunction with a suitably measured constant of the apparatus, provides a means of calculating the conductivity.

The apparatus ordinarily used for measuring atmospheric conductivity is delicate in form and calls for expert manipu-

lation. Mr. W. E. Ramsey has devised and developed to practical form an instrument of a rugged and easily manipulated type which serves for the rapid measurement of air conductivity over wide ranges of magnitude. Figure 24 is a diagram of the apparatus which is described briefly in the caption, and Fig. 25 is a photograph of the actual apparatus.[25] It will serve to state that the apparatus can be made to operate by two slightly different principles, one convenient for high conductivities, and the other convenient for low conductivities. In the former case the apparatus produces a steady deflection of an instrument, which deflection is proportional to the conductivity to be measured. In the latter case, the instrument collects a charge for an assigned time, and is then made to give a ballistic throw upon the recording instrument, the throw being proportional to the conductivity to be measured.

Apparatus for Automatic Control of Large Currents.—There are occasions when it becomes desirable to control a current of large magnitude to a constancy of high degree. Such a situation arises in connection with the control of the current which operates the magnet of a cyclotron. Dr. W. E. Danforth[26] has devised such a scheme. The details are rather complicated for exposition here, and it will suffice to say that it has been successful in controlling a current of 165 amperes to a constancy of 0.01 per cent.

CONCLUSION.

And so once more I come to the end of what has necessarily been a rather scrappy birdseye view of our activities during the year. Men of science are accused of being the source of much tribulation in the world in these days; but while in the study of cosmic-ray phenomena we are concerned with projectiles which, per unit mass, have energies trillions of times the energies of the projectiles of war, and to whom the thickest armor plate is but as tissue paper, these projectiles confine

[25] At this point the apparatus was demonstrated in its action in measuring the ordinary conductivity of the air in the lecture room and in measuring the conductivity when enhanced ten-fold by artificial means. For purposes of lecture demonstration the small portable galvanometer associated with the apparatus was replaced by an ordinary mirror galvanometer with a spot of light deflected on to a screen.

[26] W. E. Danforth, *Rev. Scient. Instr.*, 10, 211 (1939).

their terrors to the atomic world. In the fires of the sun, we find the tremendous forces of atomic physics playing an active rôle in phenomena on a large scale; but as yet, and perhaps it is as well that it is so, these forces are outside of the realm of man's control except for the mild control which he exerts upon them in the experiments by which he studies them.

APPENDIX.

PUBLICATIONS OF THE BARTOL RESEARCH FOUNDATION FROM APRIL 20, 1938 TO APRIL 19, 1939.

Note on the Variation of the Production of Bursts of Ionization with Thickness—C. G. MONTGOMERY AND D. D. MONTGOMERY. JOUR. FRANK. INST., **225**, No. 5, pp. 585–586, May, 1938.

Measurement of the Radiofrequency Voltage in a Cyclotron—W. E. DANFORTH AND M. B. SAMPSON. *Rev. Scient. Instr.*, **9**, No. 6, pp. 175–178, June, 1938.

Radioactivity of Be^7—R. B. ROBERTS, N. P. HEYDENBURG AND G. L. LOCHER. *Phys. Rev.*, **53**, No. 12, p. 1016, June 15, 1938.

The Multiplicative Theory of Showers as Applied to Large Bursts of Cosmic-Ray Ionization—C. G. MONTGOMERY AND D. D. MONTGOMERY. *Phys. Rev.*, **53**, No. 12, pp. 955–959, June 15, 1938.

Circuits for the Control of Geiger-Mueller Counters and for Scaling and Recording Their Impulses—T. H. JOHNSON. *Rev. Scient. Instr.*, **9**, No. 7, pp. 218–222, July, 1938.

Cosmic-Ray Electron Showers in a Mine 100 Feet Below Sea-Level—W. F. G. SWANN AND W. E. RAMSEY. *Phys. Rev.*, **54**, No. 3, pp. 229–230, August 1, 1938.

The Cosmic-Ray Intensity at High Elevations in Northern Latitudes—T. H. JOHNSON. *Phys. Rev.*, **54**, No. 3, pp. 151–152, August 1, 1938.

A Neon Tube Coupled Amplifier Circuit for Radio Cosmic-Ray Receivers—S. A. KORFF. *Rev. Scient. Instr.*, **9**, No. 8, pp. 256–257, August, 1938.

The Hard and Soft Component of the Cosmic Radiation in Terms of a Common Primary Background—W. F. G. SWANN. *Phys. Rev.*, **54**, No. 4, p. 307, August 15, 1938.

Bursts in Cosmic Radiation in the Equatorial Zone—S. A. KORFF. *Terr. Mag. and Atmos. Elect.*, **40**, No. 3, pp. 227–230, September, 1938.

A Note on the Nature of the Primary Cosmic Radiation—T. H. JOHNSON. *Phys. Rev.*, **54**, No. 5, pp. 385–387, September 1, 1938.

Report on the Work of the Bartol Research Foundation, 1937–38—W. F. G. SWANN. JOUR. FRANK. INST., **226**, No. 4, pp. 441–503, October, 1938.

Correlation of Cosmic-Ray Geomagnetic Effects—T. H. JOHNSON. JOUR. FRANK. INST., **226**, No. 4, pp. 533–538, October, 1938.

Cosmic-Ray Intensity and Geomagnetic Effects—T. H. JOHNSON. *Rev. Mod. Phys.*, **10**, No. 4, pp. 193–244, October, 1938.

Nuclear Transmutations of the Lithium Isotopes—L. H. RUMBAUGH, R. B. ROBERTS AND L. R. HAFSTAD. *Phys. Rev.*, **54**, No. 9, pp. 657–680, November 1, 1938.

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The State University of Iowa, Iowa City, Iowa, November 21, 1938.
Philosophical Approach to the Quantum Theory—W. F. G. SWANN.
What has Become of Reality in Modern Physics?—W. F. G. SWANN.

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Evidence as to the Nature of the Primary Cosmic Radiation—T. H. JOHNSON.

Philosophical Society of Washington, Washington, D. C., March 25, 1939.
Recent Advances in Cosmic-Ray Investigations (Joseph Henry Lecture)—T. H. JOHNSON.

Lightning Strokes in Field and Laboratory.—In the November 1939 JOURNAL OF THE FRANKLIN INSTITUTE mention was made of "hot" lightning which emanates from a generator of a different high voltage type from the usual, in that the discharge contains the components of natural lightning. Mr. P. L. Bellaschi of the Westinghouse Electric and Manufacturing Co., Sharon, Pa., summarizes in *Electrical Engineering*, Vol. 58, No. 11, recent developments in the lightning stroke generator which have made substantial contributions to lightning research. High current components and the long duration components of low current in lightning strokes have been recorded by the oscillograph in field investigations in Europe. From tests of the lightning stroke generator and other findings it is clearly apparent that shattering, bursting, explosive effects, and similar damage to objects hit by lightning are caused largely by high current short duration discharge of the stroke, whereas fires, heavy fusion of metal, fulgurites, extensive burning, and other similar effects result largely from relatively low current components, that may be sustained even for a substantial fraction of a second. The thunder following the lightning flash results from the explosive expansion of the channel and is due to the high current initial discharge. Strokes to or from elevated objects, between clouds, and under special conditions have been observed in which the current is largely a long duration component. Such discharges are not accompanied by appreciable noise.

R. H. O.

GROWTH HORMONES IN PLANTS.*

BY

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The development of our knowledge of the plant hormones is a very interesting example of how a piece of research which seems purely academic may lead to results of considerable practical importance. It also demonstrates rather well the reason for the fascination of scientific work, because one never knows quite where one is going to be led next. Almost any research problem becomes a kind of chase, with all the excitement of an old-time comedian's chase, which may embroil him in all kinds of difficulties and may finally land in the most unexpected places.

No scientific story, of course, has a true beginning, for they all grow out of some earlier one, but this may be regarded for the present as beginning in 1919, when Professor Paál, in Hungary, was studying the response of certain seedlings to light. For this work he used the coleoptiles of the cereals, especially oats.

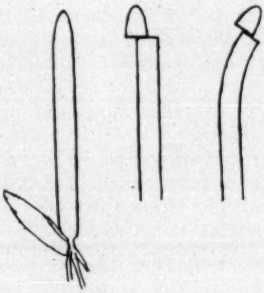
In a field of oats or wheat, when the crop is still young, one may readily see a thin papery sheath at the base of the stalk. It is soon torn open by the leaves which grow up through it, and withers early. This delicate shoot first attracted the attention of Charles Darwin by its extreme sensitivity to light, and since Darwin many others have studied it. Now Paál was interested in the effect of the extreme tip of the coleoptile on the sensitivity of the part below it. He was anxious to confirm the earlier finding of Boysen-Jensen (1913), which was that if the tip is removed, the sensitivity to light—as shown by the curving of the coleoptile towards the source of light—was lost, and that when the tip was replaced (not grafted but just glued on) this sensitivity returned. He not only did confirm this, but

* Presented at a meeting held Thursday, March 9, 1939.

found something even more important. If the tip which had been cut off was stuck on again a little to one side, the side on which it rested grew more than the opposite side, with the result that the plant curved (Fig. 1). No light was here involved; the curvature was due to the one-sided influence of the tip. Paál deduced that the growth of the shoot was controlled by a growth substance or hormone which was produced by the tip.

Now the idea of hormones was developed by zoölogists to account for those phenomena in which one organ influences

FIG. 1.



The experiment of Paál. Left, intact seedling; center, tip removed and replaced to one side; right, curvature resulting.

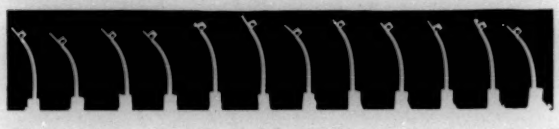
the whole of the rest of the body. The heroine of the dime novel, who is suddenly confronted by the villain, or by the family ghost, turns as white as a sheet, her hair stands on end, and her eyes widen with horror. These effects result from her having received a dose of a hormone (adrenalin) which is secreted in a special gland and travels about in the blood stream, causing the capillaries to contract all over the skin and scalp. Many other hormones are known. All of them are secreted in some part of the animal body and travel about it to exert their effects in other parts.

In this case growth is controlled by a substance or hormone secreted by the tip and travelling down the side of the plant, which responds by growing faster. In the normal plant, with

the tip symmetrically placed, all sides would receive the same amount of the hormone and consequently would grow equally.

It was ten years before the next step forward was taken by Went, in Holland (1928). He found that if the tips were cut off and placed on a jelly of agar or gelatine, this jelly acquired the property of hastening the growth of a coleoptile stump when applied to one side of it. The growth-promoting hormone had diffused from the tip into the agar. The curvatures which resulted were very regular, and Went found that under constant conditions the reaction could be used as a test for the hormone (Fig. 2). Agar pieces of controlled size were used, and the curvature of the plants measured after a definite time. The curvature was then proportional, within certain limits, to the amount of hormone which must have entered the agar.

FIG. 2.



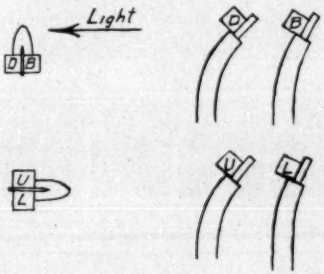
Oat seedlings with tips removed and blocks of agar containing growth hormone applied. Photographed 100 minutes later.

Instead of placing the agar on one side of the coleoptile stump it can be placed symmetrically on it, thus taking the place of the tip, with the result that the coleoptile grows faster on all sides. With a travelling microscope the straight growth can also be used for the assay of the growth hormone. This is important in principle, but the curvature method has certain technical advantages for use as a routine test.

Now there are a good many natural conditions under which plants curve. Plants are not free to move about as the higher animals are, since their base is usually fixed. When one is confined to bed by doctor's orders, one's base is similarly fixed, and about all that one can do, when receiving visitors, is to curve in various ways. Plants curve in particular in response to light and gravity. In these curvatures there is a characteristic difference between the response of the shoot and that of the root. Shoots curve *towards* a weak

light, while the roots are either indifferent or (in some plants) curve away from the light. Shoots curve upward away from the earth, roots typically downward. As mentioned above, it was from studies of the curvature toward light that the role of the growth hormone was discovered. Naturally, therefore, it occurred to these workers that the curvatures caused by asymmetric application of the growth hormone are probably related to those due to light and gravity. Cholodny, in Russia (1927), suggested that all such curvatures were due to a displacement of the hormone within the plant, more going to the lower side when the plant is placed horizontal, or to

FIG. 3.



Above: light coming in direction of arrow causes more hormone to diffuse out from the dark side *D* than from the bright side *B*.
Below: gravity acting on the tip placed horizontal causes more hormone to diffuse out from the lower side *L* than from the upper side *U*.

the shaded side when exposed to a one-sided source of light. That this is the correct explanation was proven in the following way: tips were cut off and placed on two small pieces of agar so that the hormone diffusing from the two sides would be collected in separate pieces. On now exposing to light from one side, the agar on which the shaded side rested was found to contain more growth hormone than the other. The amounts of growth hormone were determined by applying the agar to other plants from which the tips had previously been removed, and measuring the curvature. In the same way tips were placed horizontal and the agar in contact with the lower side was then shown to have more hormone in it

than that in contact with the upper side (see Fig. 3). These experiments have since been repeated in a variety of plants and they leave no doubt that this is at least the major factor in the production of such curvatures.

It was not long before chemical work on the nature of the hormone was undertaken. This was made possible by the discovery that it is present, in much larger quantity than in the coleoptile tip, in cultures of some bacteria and fungi, and in human urine. Kögl and Haagen Smit, in Holland (1931–4), isolated three active substances from urine and also from corn seeds, while I isolated (1935) the substance produced by the fungi and found it to be identical with one of their compounds. Since then other active compounds have been synthesized, and we now have a variety of these substances, which all have about the same effect, though in different degree. They have been called "auxins."

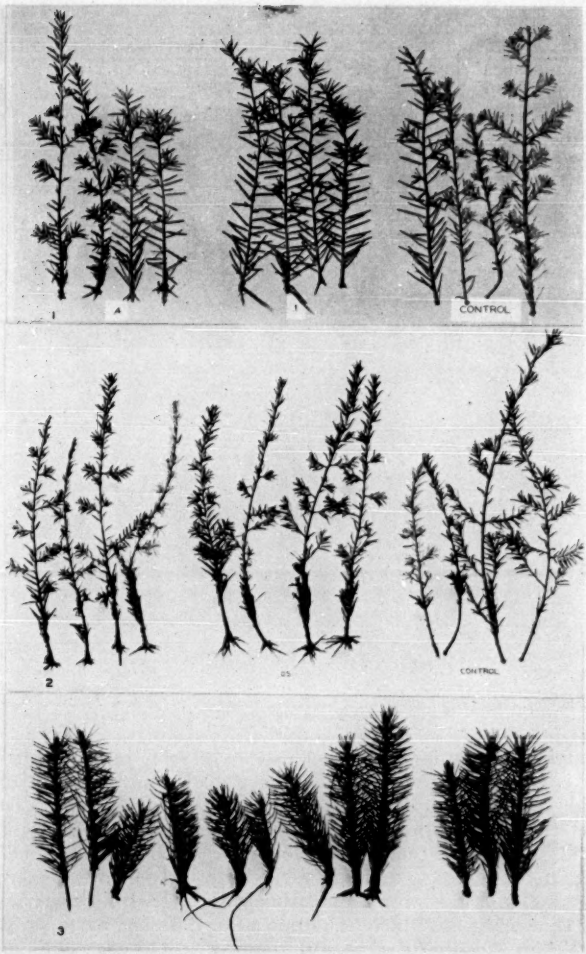
While this work was developing we made a survey of the distribution of auxin in the whole plant. It was found that it is formed mainly in growing buds and in young leaves. This had an important sequel. As is well known, plants usually have a "leader" or terminal bud. If this is cut off, one of the other buds begins to grow and soon becomes the leader. In other words, this bud was capable of growth all the time, but did not do so because the terminal bud was present, i.e. it was *inhibited* by the terminal bud. Now since the terminal bud produces relatively large amounts of auxin, Skoog and I made the experiment (1934) of removing this bud and putting in its place a supply of auxin. The buds below were then inhibited to the same extent as they would have been by the terminal bud. The auxin which this bud produces, then, has two functions;—it causes the stem below it to grow, and it causes the buds below it to be prevented from growing. This is the first example of what was later found to be very general, namely that auxin elicits different responses from different plant parts. Although normally it causes the stems to grow while the buds are inhibited, it must not be thought that this is simply a balance or a compensation of growth, i.e. that if the stem grows the buds do not and *vice versa*. For we found that it is possible by using the right conditions to prevent the growth

of the buds without causing the stem to increase appreciably in length. In other words, the inhibition is quite independent of other growth processes.

At the same time as this work was done we were engaged in the study of another problem. It is known that isolated parts of stems, i.e. cuttings, form roots under certain conditions. Generally cuttings root better if young buds or leaves are on them. On this account it was thought possible by van der Lek and by Went (1929) that the *formation* of roots is controlled by a hormone. Went and I (1934) soon found that certain preparations when applied to cuttings which otherwise were not in the condition to root (having been kept in the dark) caused rooting, and that the number of roots formed could be made roughly proportional to the concentration of the material used. Work was therefore begun on the purification and isolation of the active *root-forming* hormone. It was not long before it became clear that the richest sources of this were the same materials which had proven rich sources of auxin, namely urine and the cultures of fungi already mentioned. On successive stages of purification of the root-forming hormone its activity always went along with the auxin activity. Finally we became convinced that the root-forming hormone is identical with the growth hormone, auxin. This was proven when we synthesized an auxin (indolè-acetic acid, which Kögl and Haagen Smit had just isolated from urine and shown to be an auxin) and found it to be highly active in producing roots. Furthermore, the production of roots, like the promotion of growth, is general and not limited to special groups of plants, so that the use of auxins in promoting the rooting of cuttings by nurserymen has since that time become widespread. Several synthetic auxins have been marketed for this purpose.

Although the results of auxin treatment in rooting of cuttings are in general very striking, there are some plants which do not respond markedly even to this. Recently we have studied some of these so-called "difficult" plants. It appears that some of them, such as Canadian hemlock and blue spruce, may be readily rooted if care is used, and auxin in the right concentration is applied (Fig. 4). Some others, such as white pine and Norway spruce, can also be rooted,

FIG. 4.

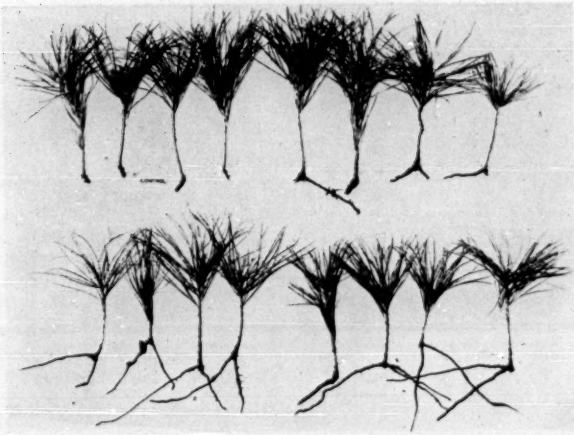


Top, Canada hemlock. Left to right, 400, 100, and 0 mg. auxin per liter for 24 hours.
Middle, Canada hemlock, variety *pendula*. Left to right, 100, 50, and 0 mg. auxin per liter for 24 hours.
Bottom, Blue spruce. Left to right, 400, 200, 100, and 0 mg. auxin per liter for 24 hours. All photographed after 9–10 weeks in peat-sand medium. (From Thimann, K. V. and Delisle, A. L., *Journal of the Arnold Arboretum*, 20, 116–136, 1939.)

but only when the plants from which cuttings are taken are themselves young (Fig. 5). It is important to note that it is not the age of the cutting which is important, but the age of the tree from which it is taken. Occasionally, too, other substances, such as sugar, vitamin B, etc., when used together with auxin, promote the formation of roots.

Another fact of some importance in the rooting of woody

FIG. 5.



White pine. Left to right, above, 0 and 100; below, 200 and 400 mg. auxin per liter for 24 hours. Photographed after four months.

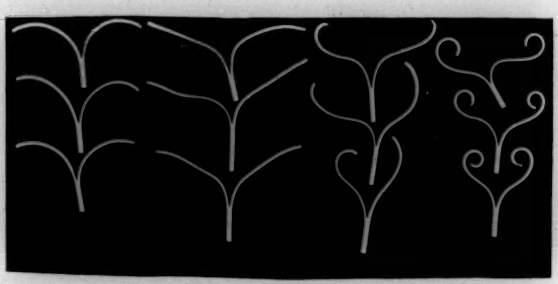
cuttings is the type of shoot used. In some of the conifers it is clear that there is a difference in response between the side shoots (laterals) and the apical or terminal shoot. The latter, even if supplied with sufficient auxin, roots less readily and dies more quickly than the side shoots. Thus here again the response to auxin varies with the part of the plant.

Perhaps the most remarkable variation within the plant is shown by the different responses of different parts within the same section of stem. If stems of young pea plants are slit in two and placed in auxin solution, the two halves curl

inward towards each other. The extent of the curvature varies with the concentration of the solution, and the reaction can thus be used as a test for the auxins (Fig. 6). Many other plants show the same phenomenon; dandelion stalks are very responsive. The development of the curvature can best be shown in the form of a movie, taken by lapsetime photography. The halves first curve outwards, then after an hour or so the inward curve begins and is complete in about 20 hours.

Now in this reaction the auxin is being supplied to all the tissue, since the piece of stem is immersed in the solution,

FIG. 6.



Inward curvature of slit stems in auxin solutions. Left to right; water, 0.2, 1 and 5 mg. auxin per liter. Photographed after about 30 hours.

yet nevertheless the curvature which results shows that the tissues on the outside grow more than those on the inside. It is evident that this phenomenon is quite different from those described at the beginning, in which curvature results because the auxin is only applied to one side. We have accumulated a good deal of evidence to prove that here there is truly a difference in the response of the outer and inner sides to the same auxin concentration.

Such subtle differences as this between closely appressed layers of tissue, or those described above between the rooting response of different parts, can now be investigated for the first time by the use of growth hormones. These substances are a powerful tool for studying all kinds of phenomena in

plants and especially that most obscure process of all, whose understanding is one of the most fundamental things with which biologists are concerned, the phenomenon of growth.

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BACTERICIDAL IRRADIATION OF AIR.*

PART I. PHYSICAL FACTORS.

BY

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Disinfecting processes have usually been studied under uniform concentrations or intensities of lethal agents. A relatively uniform chemical concentration, a relatively uniform temperature, or a relatively uniform intensity of light has usually been applied in practical disinfection. Within reasonable limits, the death rate of homogeneous living elements is approximately constant if the concentration or intensity of the lethal agent is maintained constant, thus: [1]

$$-dN/N = \alpha dt \qquad \text{or} \qquad N/N_0 = \exp[-\alpha t]. \qquad (1)$$

Within similar limits the death rate of elementary organisms subjected to a given source of ultra-violet radiation will be proportional to the light intensity; [2] hence

$$\alpha = K_0 I$$

or

$$N/N_0 = \exp[-K_0 I t]. \qquad (2)$$

These formulae depend upon the basic assumption that the

* This study, commenced under a grant from the Milton Fund of Harvard University for studies on the effects of ventilating factors on dispersion and viability of microorganisms suspended in air, is continued under a grant from the Commonwealth Fund to the University of Pennsylvania for investigations of air-borne infection, with laboratories in the Department of Bacteriology, the Children's Hospital and the Henry Phipps Institute for the Study, Treatment and Prevention of Tuberculosis.

[1] Rahn, O., "Physiology of Bacteria," P. Blakiston's Son and Co., Philadelphia, 1932. In Part D, Mechanism of Death, Rahn discusses fully, with basic references, the logarithmic nature of bacterial mortality in terms of the unimolecular reaction rate.

[2] Bunsen, R. W. E., and Roscoe, H. E., *Ann. der Physik*, 117: 529, 1862. Rigid demonstration of the reciprocity law has been theoretically disputed, but the practical application to disinfection may be as useful as in photography.

number of bacteria killed will be proportional to the light energy intercepted by the living organisms.[3] The vulnerability constant K_0 for any organism may be specified in terms of the vulnerability of a particular organism, such as *Esch. coli*, taken as unity.

It is convenient to define the intensity I in terms of the distance (r) from a generative source I_0 by the inverse square law, when equation (2) becomes:

$$N/N_0 = \exp\left[-K_0 I_0 t/r^2\right]. \qquad (3)$$

Obviously I_0 defines the bactericidal power of a point source.

These simple equations suffice in studies of lethal radiation where bacteria are exposed on fixed surfaces equidistant from the source, or in volumes so small that intensity differences throughout the volume may be neglected. Though lethal photons are not, like lethal molecules, distributed uniformly throughout disinfected space, these equations can, with appropriate coefficients, also be practically applied to varying intensities in the bactericidal irradiation of air.[4] Derivations of coefficients are given in the appendix. The results are as follows:

INFINITE MIXING.

Mathematical integration of exposure depends upon assumed positions of living organisms throughout the disinfected space during each disinfecting instant of time. Uniformity of exposure may be approached by spatial distribution of living organisms in time, as well as by distribution of light in space. Infinite mixing of the living organisms at every instant would have the same effect as uniform mixing of the light, permitting the substitution of the average intensity $\bar{I}$ throughout the volume for I in equation (2).

This represents the limiting case of maximal disinfection [3] in a given space by a given quantity of light. Since uniform density of living organisms would be maintained with infinite mixing, the probability of any light ray being intercepted by a

[3] Wells, W. F., "Air-borne Infection and Sanitary Air Control," *J. Indus. Hyg.*, 17: 253, 1935.

[4] Wells, W. F. and Wells, M. W., "Air-born Infection. Sanitary Control," *J. A. M. A.*, 107: 1805, 1936. (See footnote.)

living organism would be generally proportional to the length of the ray, and in every spherical shell with a light at the center, or every sector of spherical shells of equal thickness cut by a central solid angle, an equal number of organisms would be killed.

In a sphere with light source at the center, the average killing rate is three times that at the periphery. Thus where ρ_0 represents the initial density and ρ the density at time t,

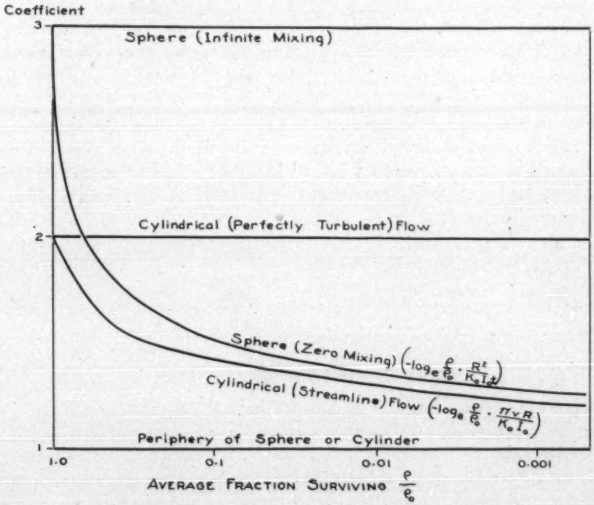
$$\rho/\rho_0 = \exp\left[-3K_0I_0t/R^2\right]. \qquad (4)$$

(Cf. equation (11) of appendix.)

ZERO MIXING.

Under the equally impossible condition of zero mixing, i.e., organisms fixed in space, the minimal lethal effect is theoretically realized. The integral in this case (viz. equation (13)

FIG. 1.



Coefficient plotted against average fraction of surviving organisms.

of appendix) does not yield an exact formula in convenient form. The initial death rate is identical with the maximum derived for infinite mixing but a concentration gradient is immediately established. On this gradient the concentration at points $R/\sqrt{3}$ distant from the center remains equal to that for infinite mixing, but the average disinfection rate falls, at first rapidly, then more and more slowly, toward that at the periphery.

The average disinfection rate over a wide range of significant killing is found by graphic solution (see Fig. 1) to be approximately 1.28 times that at the periphery, and the average concentration therefore approximates closely that at points $R/\sqrt{1.28}$ distant from the center. So where ρ represents the mean density at time t,

$$\rho/\rho_0 = \exp\left[-\,1.28K_0I_0t/R^2\right]. \qquad (5)$$

(Cf. equation (14) of appendix.)

Neither the coefficient for infinite nor zero mixing can apply to a real atmosphere. Intermediate between the two lies the value of some coefficient depending upon the ratio of mixing velocity to killing rate which describes the actual conditions.

UNIFORM LINEAR FLOW DIRECTLY APPROACHING LIGHT.

More precise and convenient experimental methods for integrating the product of lethal intensity and exposure time may be developed by measuring the bacterial concentration of air flowing past a light. When the air approaches a light of intensity I_0 at uniform velocity v from ∞ to a distance x from the light, equation (3) is replaced by

$$\rho/\rho_0 = \exp\left[-\,K_0I_0/vx\right]. \qquad (6)$$

(Cf. equation (19) of appendix.)

UNIFORM LINEAR FLOW PASSING LIGHT.

If the air passes in a straight line at a distance y from a source, the density of bacteria decreases in accordance with the equation

$$\rho/\rho_0 = \exp\left[-\,\pi K_0I_0/vy\right] \qquad (7)$$

in going from $-\infty$ to $+\infty$. (Cf. equation (18) in appendix.)

STREAM LINE CYLINDRICAL FLOW.

With a stream line flow, the case of minimal killing, the exact integral (see appendix) again proves of little practical value, but (with an approximation even closer than in the corresponding case of the sphere) differs only by an exponential coefficient from equation (9) for maximal killing. The average disinfection rate is found by graphic solution (see Fig. 1) to be approximately 1.24 times that at the periphery. Thus where ρ represents the mean density at ∞,

$$\rho/\rho_0 = \exp\left[-1.24\pi K_0 I_0/vR\right]. \qquad (8)$$

(Cf. equation (20) in appendix.)

TURBULENT CYLINDRICAL FLOW.

Perfect turbulence (in which uniform concentration is maintained within each section of a cylinder normal to the line of flow) corresponds to infinite mixing in a sphere. The average disinfection throughout a cylinder with light source in axis is twice that on a flow line at the periphery, and

$$\rho/\rho_0 = \exp\left[-2\pi K_0 I_0/vR\right]. \qquad (9)$$

(Cf. equation (22) in appendix.)

Perfect turbulence constitutes the limiting condition of maximal killing, and it is interesting to note [3] that it also corresponds to the condition where the velocity is inversely proportional to the distance of a flow line from the axis through the light, or where the light is distributed uniformly across the tunnel.

The average density emerging from the cylinder actually corresponds to that at an element between $R/2$ and $R/1.24$ distance from the axis to the wall of the cylinder for stream line flow, depending upon the relation between the degree of turbulence and the killing rate.

SUMMARY.

The natural logarithm of the mean bacterial density in irradiated air divided by the initial density, $\log_e \rho/\rho_0$, approximates:

A. With average lethal intensity $\bar{I}$ for time t,

$$< -K_0\bar{I}t \qquad (2)$$

(depending upon the ratio of mixing velocity to killing rate);

B. At r distance from a point source I_0,

$$-K_0I_0t/r^2; \quad (3)$$

C. With source at center of a sphere of R radius,

$$< -3K_0I_0t/R^2 \quad \text{and} \quad > -1.28K_0I_0t/R^2 \quad (4) \text{ and } (5)$$

(the actual value of the coefficient being determined by the ratio of mixing velocity to killing rate, being less for quiescent and greater for rapidly mixed air);

D. Approaching a source at velocity v, from $+\infty$ to x distance from source,

$$-K_0I_0/vx; \quad (6)$$

E. Passing the source (from $+\infty$ to $-\infty$) on a straight line y distance from source,

$$-\pi K_0I_0/vy; \quad (7)$$

F. With source in axis of cylinder of R radius (from $+\infty$ to $-\infty$),

$$< -2\pi K_0I_0/vR \quad \text{and} \quad > -1.24\pi K_0I_0/vR \quad (8) \text{ and } (9)$$

(the actual value of the coefficient being determined by the relation between turbulence and killing rate, being less for stream line flow and greater for highly turbulent flow).

EXPERIMENTAL RESULTS.

Experiments designed to determine bactericidal power by these equations serve in a measure to test the validity of the assumed time-space relationships. A smooth tunnel, 100 feet long, 8 feet wide, and 7 feet high, in the Harvard Business School became available during the brief interval between the summer and fall semesters of 1935. A standard ultra-violet quartz mercury arc was set up near the center of the tunnel.

Air flow through the tunnel was maintained by three large-capacity ventilating fans which exhausted a chamber at one end of the tunnel. At the opposite end, the incoming air received an inoculum of a diluted (about 4 per cent.), twenty-four hour, lactose broth culture of *Esch. coli* sprayed up by a Gilbert Atomizer. The air then passed through a mixing

chamber before entering the tunnel. In order to establish a uniform flow of air in the tunnel, suitable cloths were stretched over a frame at the entrance. On the front of this foot-deep frame, an adjustable orifice opening between two heavy paper curtains permitted velocities that could be measured by an anemometer hung at the center of the orifice. By varying the coarseness of the cloth screen and the number of fans in operation (and to a lesser extent, the window openings in the entrance chamber and the size of the orifice), flows varying from 4 feet per minute to more than 200 feet per minute were readily obtained.

Approaching Light.

Three air centrifuges made simultaneous collections of samples at different points in the tunnel, so that direct comparison of the bacterial content of the same air at three different points with respect to the lamp was facilitated. Standard samples of 10 cubic feet of air were taken, in successive sets of three, at five-foot intervals from 5 to 55 feet, as the air approached the light.

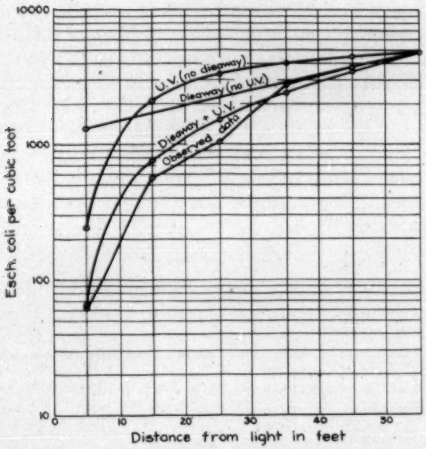
In a trial test, with air velocities above 50 feet per minute, no decrease in the number of organisms was observed. In the next run (Table I), with velocities less than 2 feet per minute, a definite reduction of the colon bacilli was observed as far as 40 feet from the light. Determination of air flow at these

TABLE I.

Approaching Light.

Date, 1935.	Relative Humidity Per Cent.	Velocity Ft. per Minute.	*Esch. coli* per Sample. Given distance from light (feet).					
			55	45	35	25	15	5
8/29	50	1.8	1,172	720	222	143	98	4
8/30	90	11.4		29,200	31,200	18,200	18,800	5,350
8/30	90	17.3		49,500	23,200	7,210	21,600	18,400
9/3	71	3.9	4,100	3,600	2,580	444	168	13
9/4	74	6.0	5,690	3,840	3,000	2,480	1,930	303
Light off								
8/30	90	17.3			43,300			45,800
9/4	74	7.5		9,720		8,800		7,870

FIG. 2.



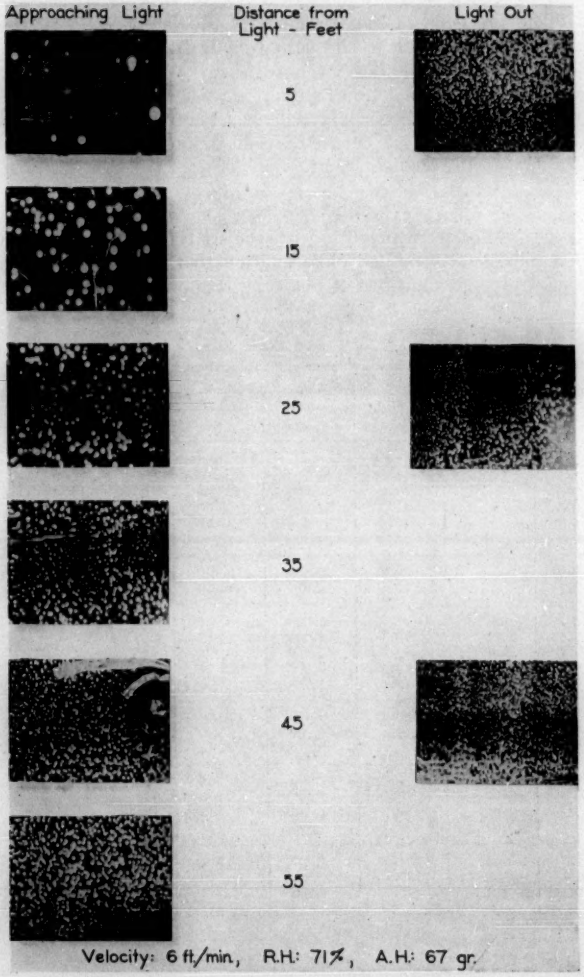
Death of *E. coli* in air approaching ultra-violet light placed in tunnel.

low velocities was, however, inaccurate and the results were not sufficiently consistent for mathematical consideration.

With air flow increased to 11 feet per minute, the results showed a marked reduction near the lamp. At 17 feet per minute, even this effect became negligible.

Finally two well-controlled runs at velocities of 4 and 5 feet per minute yielded results admitting of closer analysis (Chart I). Means of the two runs do not, however, follow from the formula derived above, because at these velocities a simultaneous reduction by natural processes within the time intervals between sampling becomes appreciable. By combining with the equation for normal death rates, $\log_e N/N_0 = ct$, it is possible to solve (Fig. 2) for appropriate values for K_0I_0 (82) and c (.13). The value of c, so determined, checks reasonably well with values obtained in a previous study and the value of K_0I_0 compares favorably with those found in the second series of more determinate experiments discussed below.

CHART I.



Bactericidal action of ultra-violet radiation on *E. coli* in air approaching the light.

The precision of measurement of the factor $K_0 I_0$ by the method of approach to the light was limited in these experiments. When the flow was sufficiently high for reliable measurement, the bacterial reduction was too low for accurate determination. Conversely, when the bacterial reduction was sufficiently high for accurate determination, the flow was too low for reliable measurement.

Passing Light.

It did not seem possible with the spatial arrangements in this tunnel to approach close enough to the light to obtain accurate determinations of bacterial reductions at flows high

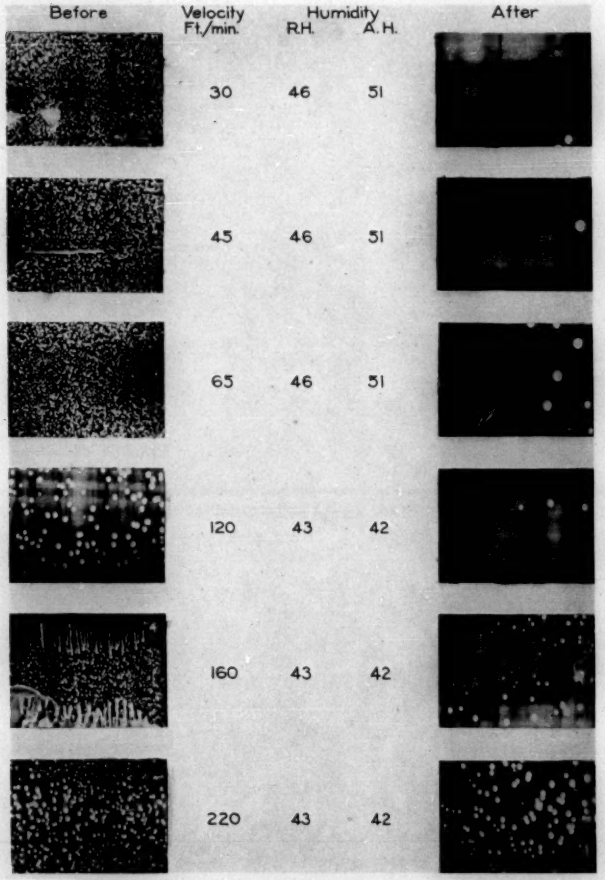
TABLE II.

Passing Light.

Date, 1935.	Relative Humidity.	Velocity Ft. per min.	*Esch. coli* per sample.		*	Average.
			Before.	After.		
		v.	ρ_0.	ρ.	$K_0 I_0$.	
9/5	67	21.1	42,000	12,500	23.3	29.6
9/5	67	37.7	31,600	9,760	40.3	
9/5	67	40.5	30,800	4,488	28.1	
9/5	67	44.0?	34,200	17,500	26.8	
9/6	82	20.8	40,500	10,200	26.0	23.2
9/6	82	10.8	8,810	1,120	20.4	
9/7	46	65.7	7,040	12	146.	199.
9/7	46	43.3	4,800	3	292.	
9/7	46	27.4	7,880	2	206.	
9/7	46	19.3	6,260	1	153.	
9/7	46	10.4	3,650	0		
9/9	91	39.0	19,300	10,500	21.6	22.9
9/9	91	27.2	22,700	7,530	27.3	
9/9	91	6.2	6,430	234	19.9	
9/10	62	70.	13,500	792	180.	177.
9/10	62	78.	7,060	1,260	122.	
9/10	62	81.	4,840	588	155.	
9/10	62	144.	2,610	384	252.	
9/11	43	161.	4,230	711	260.	269.
9/11	43	120.	324	30	260.	
9/11	43	222.	1,250	303	288.	

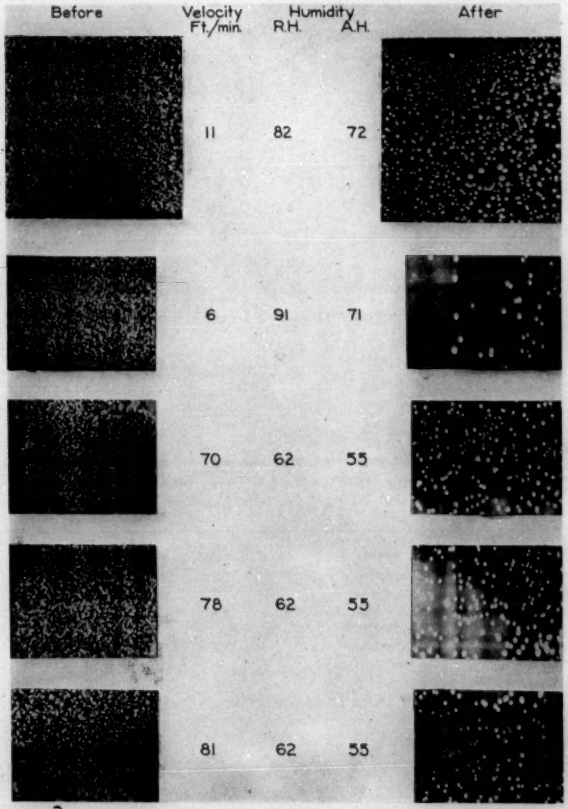
* $-\frac{3.5v}{1.24\pi} \times \log_e \frac{\rho}{\rho_0}$.

CHART 2.



Bactericidal action of ultra-violet radiation on *E. coli* in air passing the light.

CHART 3.



Bactericidal action of ultra-violet radiation on *E. coli* in air passing the light, showing effect of varying humidity.

enough for reliable measurement. It seemed possible, however, in passing the zone of major lethal intensity (obviously the zone 5 feet before and 5 feet beyond the light) to obtain bacterial reductions high enough for accurate determination at flows high enough for reliable measurement. By placing one machine 20 to 30 feet downstream from the light, and sampling simultaneously at a similar distance upstream, marked reduction was observed up to velocities of 222 feet per minute.

The bactericidal effects in passing the light at six widely differing velocities but otherwise comparable conditions are illustrated on Chart II. More than half of the bacteria were killed at a velocity of 220 feet per minute and yet some survived passage at a velocity of 30 feet per minute, which represents more than seven times the exposure.

Values of $K_0 I_0$, computed from the data in Table II by equation (8) with an assumed equivalent radius of 3.5 feet, have been plotted on Fig. 3 against the reciprocal of the velocity. The plotted values can be reasonably fitted by two straight lines. The steeper line represents the wide range of velocities indicated on Chart II. Two tests represented on the other line are illustrated on Chart III.

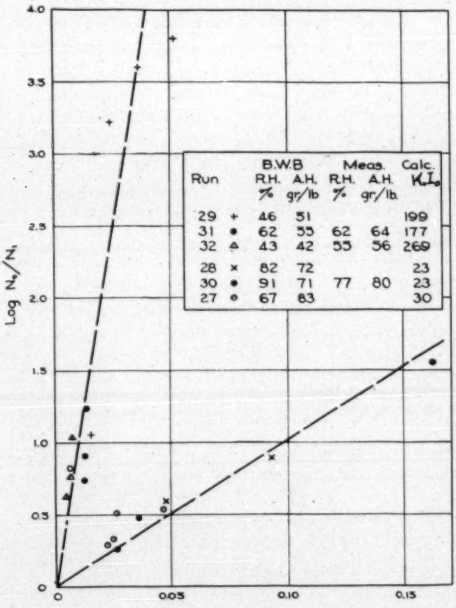
Effect of Humidity.

In seeking an explanation of the striking divergence of the lines, it was soon discovered that values from tests made on the same day were consistent. High values of $K_0 I_0$ were obtained on clear dry days while low values were obtained on damp rainy days. Fortunately this humidity effect was discovered in time to repeat tests under sufficiently different weather conditions to approximate the magnitude of the phenomenon (Fig. 3). Comparison of Charts II and III shows almost similar bacterial reduction at a velocity of six feet per minute on the latter and at a velocity of sixty-five feet per minute on the former. This ten-fold difference in killing power of the same light corresponds to a difference between a relative humidity of 46 per cent. and 91 per cent.

Obviously humidity becomes a basic factor governing the bactericidal effect of ultra-violet radiation upon microörganisms suspended in air.[3]

These exploratory tests aimed merely to determine the practical bactericidal range of an ultra-violet light by an experimentally determinate method. The consistency of the results over a wide range of velocities, when analyzed by the

FIG. 3.



Effect of humidity on death of *E. coli* passing ultra-violet light in tunnel.

formulae derived above, offers reasonable confirmation of the validity of the basic assumptions. More accurate determinations, with a more refined apparatus for testing the bacterial reduction in approaching a light, have since been obtained by B. A. Whisler [5] who assisted me in these experiments. They

[5] Whisler, B. A., Graduate Thesis, Harvard Graduate School of Engineering, June, 1936.

further confirm the validity of the time-space relationships[2] predicted in these formulae, and the effect of humidity[3] upon the bactericidal effect of ultra-violet light upon microoargnisms suspended in air.

LETHAL IRRADIATION.

Adoption of convenient units[6] of lethal irradiation will greatly facilitate the development of a practical art of ultra-violet disinfection in sanitary ventilation. If the death of an elementary standard organism be regarded as a unit of lethal work, this biophysical abstraction may be expressed in physical dimensions by means of the foregoing formulations.

"In the language of a quantum interpretation the average number of effective absorptions per bacterium"[7] becomes by (1) $-\log_e N/N_0$. The quantity of lethal radiation per unit area, to which each organism is exposed ($L = It$), is such that the number of effective absorptions equals the number of organisms when $-\log_e N/N_0 = 1$ or $N/N_0 = e^{-1} = 36.8$ per cent.

Lethal Exposure.

A unit of lethal exposure, appropriately termed a *lethe*, may therefore be defined as the uniform exposure from which 36.8 per cent. of the standard organisms (*Esch. coli*) survive.

The biological factors to be satisfied in the experimental evaluation[4] will be considered in Part II of this paper, but the importance of humidity has already been emphasized. Due regard for technical accuracy should provide a system of

[6] Luckiesh, M., and Holladay, L. L., "Nomenclature and Standards for Biologically-Effective Radiation," *J. Optical Soc. Amer.*, **21**: 420, 1931. Luckiesh, M., and Holladay, L. L., "Fundamental Units and Terms for Biologically-Effective Radiation," *J. Optical Soc. Amer.*, **23**: 197, 1933. Various types of units of biologically-effective radiation have been proposed. Units of illumination are sensory in nature. Useful as are erythemal units in physical therapy, they are still subject to individual variation. A lethal unit, the *lethe*, is more objective than either and can, in fact, be determined by measuring instruments comparable in directness and precision with the measurement of the physical radiation involved.

[7] Wyckoff, R. W. G., and Rivers, T. M., *J. Exp. Med.*, **51**: 921, 1930. Wyckoff, R. W. G., "Killing of Colon Bacilli by Ultra-Violet Light," *J. Gen. Physiology*, **15**: 351, 1932

measurement of air disinfection by radiant energy quite as precise as that practically applied in illumination.

Lethal Intensity.

The unit of lethal intensity becomes the lethal flux density which exposes an organism to one *lethe* in a unit of time. This value I is obtained from equation (2) when time is expressed in the units chosen. For the practical solution of problems of sanitary ventilation the minute is a convenient unit of time.

Lethal Radiation.

A unit of lethal radiation, emitted from a point source, exposes microörganisms at unit distance to a *lethe*. The unit of length adopted in architectural design dictates the most practical unit of distance in sanitary radiation. The foot is therefore a useful unit in English and American practice.

Lethal Power.

The number of units of lethal radiation per unit time defines the lethal power I_0 of a source. The value I_0 for a point source is given by equation (3) in terms of units chosen.

Lethal Irradiation.

Lethal irradiation or the amount of sanitary disinfection per unit volume accomplished in an enclosed space, as determined by the substitution of the appropriate coefficient of mixing, is given in a sphere by equations (4) and (5). A similar expression of lethal irradiation of organisms moving toward or past a light under conditions of flow defined in the development of equations (6) and (7) is provided by those equations. Similarly the lethal irradiation per unit volume of air flowing through a cylinder, with due provision for the appropriate coefficient of turbulence, is provided under ideal conditions by equations (8) and (9).

It is possible to generalize upon lethal irradiation per unit volume of ventilated space, or to generalize upon disinfection in terms of sanitary ventilation by integrating lethal exposure bacteriologically, $\log_e N/N_0 = -K_0 I_e t$.[8] Disinfection rates

[8] Wells, W. F., and Wells, M. W., "Measurement of Sanitary Ventilation," *Am. J. Public Health*, **28**: 343, 1938.

may then be converted into rates of pure air replacement, $\log_e N/N_0 = -Vt/V_0$, which would eliminate an equivalent proportion of the microörganisms in an equal time. *Lethes* of irradiation K_0I_e and turnovers in air replacement V/V_0 become bacteriologic equivalents.

Coefficient of Utilization.

The amount of lethal irradiation performed by a given quantity of lethal radiation depends upon the distribution of the light in space and the spatial distribution of the organisms in time. The lethal power of lights K_0I_e capable under ideal conditions of equal irradiation of equal volumes may be called effective lethal power.

It is given in a sphere by equation (4)

$$K_0I_e = -.128V^{2/3}/t \cdot \log_e \rho/\rho_0,$$

and in cylindrical flow by equation (9)

$$K_0I_e = -.09V/t\sqrt{A} \cdot \log_e \rho/\rho_0,$$

where A represents the cross section of area of the cylinder at the point of installation.

The ratio of the determined effective lethal power to the rated lethal power of the installed lights, $K_0I_e/K_0I_0 = I_e/I_0$, may be called the coefficient of utilization.

A coefficient of utilization of .33 has been easily attained in class rooms of about 6,000 cu. ft. by indirect irradiation without perceptible reflection from the ceiling and without any special provision for air movement. In a large room with uncoated plastered ceiling and walls of high reflecting value a coefficient higher than unity was obtained for a similar indirect system of irradiation.

Irradiation and Illumination.

The basic design objectives of irradiation and illumination are inverse. Illumination aims basically to provide adequate intensity at a working level. Only as a transmitting medium does space enter the problem. Until light is reflected it does not become illumination. Time and air motion are not involved. The basic specification of illumination is in the nature of a minimum intensity on a plane surface.

Light reflected from most surfaces practically ceases to be lethal. Only in space does it constitute irradiation. The basic specification of irradiation provides for a minimum interception of lethal radiation by living organisms occupying the space. Exposure time and radiation intensity are equally important factors. Air motion is the heart of the problem.

The erythemal flux at working level becomes in irradiation a maximum tolerance specification. Direction as well as erythemal intensity at the working level is important because the eye is most easily affected. Vertical downward radiation, as from the sun, is less serious than light reflected upward, as from snow or water.

The ratio of utilized lethal radiation $K_0 I_e$ throughout the space to the erythemal flux at the working level may be a determining factor in design. No difficulty has been experienced in providing 100 *lethes* of indirect irradiation per hour without perceptible erythemal intensities [9] at the working level. Over 1000 *lethes* per hour have been obtained without perceptible erythema from reflected radiation per 24 hours. Many thousand *lethes* of direct irradiation per hour have been obtained in operating rooms without perceptible erythema about the table during operating periods.

DISCUSSION.

The dependence of bactericidal action upon the quality as well as the quantity of radiation has been general knowledge from the early days of bacteriology. The lethal quality of different wave-lengths may be expressed in ergs/mm^2 per *lethe*.

Lethal Quality.

The bactericidal quality of monochromatic radiations upon bacteria planted on agar surfaces or suspended in liquids has been evaluated by many careful investigators.[10] The middle

[9] Coblentz, W. W., Stair, R., and Hogue, J. M., *Bur. Stds. J. of Res.*, **8**: 541, 1932.

[10] Gates, F. L., "A Study of the Bactericidal Action of Ultra-violet Light. III. The Absorption of Ultra-violet Light by Bacteria," *J. Gen. Physiology*, **14**: 31, 1930. Hollaender, A., and Claus, W. D., "The Bactericidal Effect of Ultra-violet Radiation of *Escherichia Coli* in Liquid Suspensions," *J. Gen. Physiology*, **19**: 753, 1936. Dreyer, G., and Campbell-Renton, M. L., "A Quantitative Study of the Action of Ultra-violet Light on Bacteria," *Proc. Royal Soc. London*, Ser. B,

ultra-violet (between 2000 Å and 3000 Å) seems to be abiotic, and more particularly those wave-lengths toward the middle of this range. While the 2640 Å wave-length is generally conceded to be more bactericidal than the 2537 Å resonance band of mercury, the practical simplicity of generating large quantities of almost monochromatic radiation of the latter wave-length peculiarly adapts it to the experimental determination of the lethal quality of radiation of this wave length upon microörganisms suspended in air. A *lethe* of exposure to a quartz mercury Geissler tube (90–95 per cent. in the 2537 Å line) [11] corresponds to 3–4 ergs per square millimeter.

While the lethal quality of monochromatic light of other wave lengths has not been determined directly against microorganisms suspended in air, the bactericidal power of a Uviarc was so determined by Whisler.[5] Weighted in accord with lethal coefficients for different wave lengths determined experimentally against *Esch. coli* planted on agar surfaces,[10] the total lethal power of the burner would be approximately 3 times that contained in the 2537 Å band, although the latter comprises only a tenth of the total ultraviolet emitted by the burner.[12] Multiplying the rated energy content of the 2537 Å light by 3 to obtain the equivalent lethal energy in terms of the 2537 Å band, we obtain a value of approximately 4 ergs per square millimeter per *lethe* of exposure when using values of $K_0 I_0$ determined by Whisler.[5]

120: 447, 1936. Coblentz, W. W., and Fulton, H. R., "A Radiometric Investigation of the Germicdal Action of Ultra-violet Radiation," Scientific Papers of the Bureau of Standards, No. 495. Note: These studies tend to confirm the approximately constant vulnerability (implicitly assumed in our formulations) of different vegetative bacteria to different wave lengths as measured against the vulnerabiliy of the standard organism (*Esch. coli*) to these wave lengths. Further argument will be based on the biological uniformity of the vulnerability constants considered in Part II of this paper. Perhaps biophysical phenomena of lethal light absorption by nucleoproteins also tend to corroborate these tentative conclusions. See Caspersson, T., "Über den Chemischen Aufbau der Strukturen des Zellkernes," *Skandinavisches Arch. f. Physiologie*, 73, Suppl. 8: 3, 1936.

[11] Maddock, A. J., "Absolute Intensities in the Spectrum of a Low-pressure Quartz Mercury-Vapour Discharge Burner," *Proc. Physical Society*, 48: 57, 1936.

[12] Forsythe, W. E., Barnes, B. T., and Easley, M. A., "Ultra-violet Sources and their Radiation," *J. Optical Soc. Amer.*, 24: 178, 1934. Barnes, B. T., and Forsythe, W. E., "Characteristics of Some New Mercury Arc Lamps," *J. Optical Soc. Amer.*, 27: 84, 1937. Buttolph, L. J., *R.S.I.*, 1: 487, 1930.

This would seem to justify the assumption that the *relative* lethal quality of the different wave-lengths in air and in water is of a similar order of magnitude.

Lethal Quantity.

Equal probability that individual organisms succumb in equal exposure intervals follows from an assumption of discontinuous units of light as well as discrete units of life, and that a particular light unit destroys a unit of life.[13] If light were continuous, no organism would succumb until a lethal quantity had accumulated, when, except for biological variation in resistance of individual organisms, all would succumb abruptly. Were light discontinuous but more than one light unit required to destroy a life unit, the death rate would increase from zero toward the maximum given by the assumption of death of a life unit produced by a single light unit. Thus when unicellular organisms are associated in groups, such as *Sarcina lutea*,[14] every cell in the group must die to prevent the development of a colony. Here a lapse of time does occur before an appreciable reduction in the number of colonies is observed, followed by a more abrupt reduction in colonies.[4] The effect of a "minimal lethal dose," observed with multicellular organisms, is simulated, and light might, from the colony counts, appear to be continuous even though the death rate of individual cells could be derived from the assumption of discontinuity.

The deduction that a single encounter between a light unit and a life unit may suffice to bring death to a cell predicates qualities of light and living units which must satisfy other quantitative observations. If, as may be readily com-

[13] Crowther, J. A., "Some Considerations Relative to the Action of X-Rays on Tissue Cells," *Proc. Royal Soc. of London*, Ser. B, **96**: 207, 1924. Crowther, J. A., "Action of X-Rays on Colpidium Colpoda," *Proc. Royal Soc. of London*, Ser. B, **100**: 390, 1926. Crowther, J. A., "The Biological Action of X-Rays—A Theoretical Review," *Brit. J. Radiology*, **11**: 132, 1938. Lea, D. E., Haines, R. B., and Coulson, C. A., "The Mechanism of the Bactericidal Action of Radioactive Radiations," *Proc. Royal Soc. of London*, Ser. B, **120**: 47, 1936.

[14] This subject will be discussed in Part II of this paper, "Biological Factors." The implicit assumption that living elements do not regenerate within the interval under test is justified by the mathematical analysis given by Swann, W. F. G., "The Effect of Radioactive Radiations upon *Euglena*," JOUR. FRANK. INST., **211**: 303, 1931.

puted from ergs per *lethe*, photons per erg and direct measurements of the cell, a half million or more photons may be intercepted without death of the average organism, some condition (in time or space) of the cell, or of these photons, must account for their failure to engage a vulnerable unit. The simple assumption of vulnerable elements of large molecular dimensions [6] might be reconciled to variation of lethal quality of different wave-lengths, were it not further complicated by our observations that an organism suspended in dry air is perhaps twenty times as vulnerable to a given wave length as when suspended in water.

This wide divergence of our results in air from those obtained with the beautiful technique of Gates and others, in liquids and on agar surfaces, might invite attention to the want of physical refinements in our experimental set-up, were it not that the simplicity and directness of our methods preclude any such discrepancies in the ratings of standard burners, the measurement of air flow, or the quantitative determinations of bacterial mortality. The difference is also consistent with the difference in dimensions adopted in the practical application of ultra-violet light to the disinfection of water and air. That our values, obtained in relatively dry air, are reduced tenfold in humid air is a phenomenon observed almost daily in laboratory routine.

The need of further investigation of the effect of radiant energy upon the viability of microörganisms suspended in air is indicated by this study. Such pronounced alteration in the vulnerability to lethal radiation of a bacterial cell suspended in air of slightly differing humidities must have profound biophysical significance.

APPENDIX.

The distribution of bacteria in space and time may be described by a function $\rho(x, y, z, t)$ which gives the number of live bacteria per unit volume at x, y, z at time t. The total number of live bacteria at time t, $N(t)$, is related to ρ by the equation

$$N(t) = \int \rho(x, y, z, t) dV, \qquad (1)$$

in which the integration extends over all space.

The density function varies with time for two reasons: first, bacteria are killed by radiation, and, second, mixing takes place because the air may circulate. In the limiting case in which there is no mixing, ρ is governed by equation (1) of the text, which becomes translated to

$$-\frac{d\rho(x, y, z, t)}{dt} = K_0 I(x, y, z)\rho(x, y, z, t), \tag{2}$$

where I is the intensity of light at the point x, y, z. The integral of this equation is

$$\rho = \rho_0 e^{-K_0 I t}, \tag{3}$$

where ρ_0 is the density at time $t = 0$.

Several special cases will now be discussed.

A. Infinitely Rapid Mixing.

The simplest case to treat is that of infinitely rapid mixing, in which ρ is the same at all points in space at any time. In this case, the number that are killed per unit time at any point x, y, z is

$$-\frac{d\rho}{dt} = K_0 I(x, y, z)\rho. \tag{4}$$

Integrating this equation over entire space, one finds

$$-\frac{d}{dt}\int \rho dV = -\frac{dN}{dt} = K_0\rho \int I dV \tag{5}$$

$$= K_0 \frac{N}{V}\int I dV$$

since $\rho = N/V$. If we set

$$\bar{I} = \frac{1}{V}\int I dV, \tag{6}$$

we obtain

$$N(t) = N_0 e^{-K_0 \bar{I} t}. \tag{7}$$

The mean intensity $\bar{I}$ may be readily computed when the source is at the center of a large sphere. In this case, I

varies with r, the distance from the center of the sphere, in the manner

$$I(r) = \frac{I_0}{r^2}, \tag{8}$$

where I_0 is the intensity at unit distance, and the volume of a spherical shell of thickness dr is

$$dV = 4\pi r^2 dr.$$

Hence,

$$\bar{I} = \frac{I_0}{V}\int_0^R \frac{4\pi r^2 dr}{r^2} = \frac{4\pi I_0}{V}\int_0^R dr = \frac{4\pi I_0 R}{V}, \tag{9}$$

where R is the radius of the sphere. If the relation

$$V = \frac{4\pi}{3}R^3$$

is used, it is found that

$$\bar{I} = \frac{3I_0}{R^2}. \tag{10}$$

Thus equation (7) is

$$N(t) = N_0 e^{-3K_0 I_0 t/R^2}. \tag{11}$$

B. Zero Mixing.

In the opposite case in which there is no mixing, we may substitute equation (3) in equation (1) and obtain

$$N(t) = \frac{N_0}{V}\int e^{-K_0 I(x,y,z)t} dV. \tag{12}$$

If the source is at the center of a sphere of radius R, it is found that

$$N(t) = \frac{3N_0}{R^3}\int_0^R r^2 e^{-K_0 I_0 t/r^2} dr \tag{13}$$

in place of (11). It is possible to evaluate this by numerical integration. When the coefficient is plotted against the survival rate it is seen in Figure 1 that a value 1.28 times that at the periphery of the sphere gives an approximate constant for practical disinfection ranges. Thus, (13) is approximately equal to

$$N(t) = N_0 e^{-1.28K_0 I_0 t/R^2}. \tag{14}$$

over the range of $I_0 t$ which is significant. It may be seen that N decreases more rapidly in the case corresponding to equation (11). (See Fig. 2.)

C. Uniform Linear Flow.

Next, consider the case in which each element of air flows linearly without mixing. It will be assumed that the lines of flow are parallel to the x axis and that the direction of flow is from $-\infty$ to $+\infty$. The time dt required to flow an increment of length dx along a line of flow is

$$dt = \frac{dx}{v}, \tag{15}$$

where v is the velocity of flow. If the normal distance of a given line from the source of light is y and the source is in the $x = 0$ plane, the decrease in density during the time dt is

$$-d\rho(x, y) = \rho(x, y)\frac{K_0 I_0}{(x^2 + y^2)}\frac{dx}{v}. \tag{16}$$

Thus if ρ_0 is the density when x is $-\infty$, the density at the point x, y is given by

$$\log\frac{\rho(x, y)}{\rho_0} = -\frac{K_0 I_0}{v}\int_{-\infty}^{x}\frac{dx}{(x^2 + y^2)}. \tag{17}$$

In the limit when x approaches $+\infty$

$$\log\frac{\rho(\infty, y)}{\rho_0} = -\frac{K_0 I_0}{vy}\left[\tan^{-1}\left(\frac{x}{y}\right)\right]_{-\infty}^{\infty} = -\frac{K_0 I_0 \pi}{vy}$$

or

$$\frac{\rho(\infty, y)}{\rho_0} = e^{-\pi K_0 I_0/vy}. \tag{18}$$

In the special case in which y is zero, equation (17) becomes

$$\rho(x, 0) = \rho_0 e^{-K_0 I_0/vx}. \tag{19}$$

It is possible to compute the fraction of survivors in the case in which the air is flowing linearly through a cylinder of radius R by use of equation (18). The total number n_0 per unit length of the cylinder at $-\infty$ is $\rho_0 \pi R^2$ and the corre-

sponding number at $+\infty$ is

$$n_\infty = \int_0^R \rho_\infty 2\pi y dy = \frac{2n_0}{R^2}\int_0^R y e^{-\pi K_0 I_0/v y} dy.$$

The coefficients obtained by numerical integration (Fig. 1) show that this relation is closely approximated in practical disinfection ranges by the equation:

$$\frac{n_\infty}{n_0} = e^{-1.24 K_0 I_0/vR}. \tag{20}$$

D. Turbulent Linear Flow.

If there is perfect mixing in the plane normal to the axis of the cylinder, ρ in (16) is independent of y. Hence, if this equation is integrated over a section of unit length at the position x along the axis it is found that

$$dn(x) = n(x)\frac{K_0 I_0}{R^2}\frac{dx}{v} 2\int_0^R \frac{ydy}{(x^2+y^2)}. \tag{21}$$

The fractional decrease in going from $-\infty$ to ∞ is given by

$$\log\frac{n(\infty)}{n_0} = -\frac{K_0 I_0}{R^2}\frac{2}{v}\int_{-\infty}^{+\infty}\int_0^R \frac{ydydx}{(x^2+y^2)}$$

$$= -\frac{K_0 I}{R^2}\frac{2}{v}\int_0^R dy\int_{-\infty}^{+\infty}\frac{d\left(\frac{x}{y}\right)}{1+\left(\frac{x}{y}\right)^2} = -2\pi\frac{K_0 I_0}{vR}$$

or

$$\frac{n(\infty)}{n_0} = e^{-2\pi K_0 I_0/Rv}. \tag{22}$$

This function decreases more rapidly than (20), showing that the bactericidal effect of the radiation is increased by mixing. (See Fig. 2.)

SYSTEM OF SCIENTIFIC UNITS.[8]

A unit of lethal radiation in a system of scientific units would be defined as the lethal radiation which gives unit lethal exposure over unit surface; unit lethal intensity as giving unit lethal radiation over unit surface in unit time; unit lethal power

as unit lethal radiation in unit time; unit lethal irradiation as unit lethal radiation through unit distance.

Dimensions in such a case should be chosen in conformity to the International system. The physical units of radiation corresponding to these biological units of radiation vary with wave-length. It is therefore necessary to evaluate the lethal effectiveness of each wave length.

For practical application in sanitary ventilation it is found more convenient to adopt the definitions developed in the text. The lethal power of available sources can be directly determined.

ACKNOWLEDGMENTS.

I am indebted to Dr. B. A. Whisler for efficient assistance in conducting the experiments and tabulating the results outlined in this paper. I have also taken advantage of the elaborated studies offered for his doctor's thesis which confirm the time-space relationships assumed in these formulations and corroborate the humidity phenomenon.

I am deeply indebted to Dr. F. Seitz for recasting the derivations given in the appendix and deducing the special cases from his generalized form, as well as for valuable suggestions in composition.

I am grateful to Dr. W. F. G. Swann for his patient guidance among the mathematical and physical pitfalls which beset the path of initiation.

To name all who have stretched out a helping hand at one time or another would be little expression of the gratitude I feel toward their generous assistance. Special mention should be given, however, to Dr. Stuart Mudd for his conscientious advice and criticism in editing the manuscript.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

EVALUATION OF FIRE RESISTANCE REQUIREMENTS.

The usual method of specifying structural fire protection has been in terms of thickness, or type and thickness, of materials. In recent years, some public requirements, such as building codes, have defined the degree of fire resistance in terms of performance in recognized furnace tests. Even so, in their application there has been little differentiation between buildings or occupancies in buildings involving high and low amounts of combustible materials.

In the period 1922 to 1926 a series of tests was conducted at the Bureau to obtain information on the intensity and duration of fires in buildings in their relation to the amount and calorific values of their combustible contents, as expressed in weight or heat units per unit of floor area or room volume, assumed uniformly distributed. The tests, which were mainly representative of office and record storage occupancies containing wood and metal furniture and paper records, were conducted in one-story fire-resistive buildings of floor area up to 30 by 60 feet and concentrations of combustible contents from 13 to 55 lb./ft.^{2} taken as uniformly distributed. These indicated fire severities equivalent to from one hour to nearly eight hours of fire exposure in the furnace test applied to determine the fire resistance of building constructions. In a later test with kerosene having a calorific value per pound of over twice that of wood and paper a little lower fire severity was indicated than with an amount of wood and paper having equivalent fuel value.

To aid in applying fire-resistance requirements a survey was made of combustible contents of a number of public and private fire-resistive office buildings in Washington. These indicated a range from less than 5 up to 80 lb./ft.^{2}, assumed uniformly distributed, the lighter contents applying to executive offices and reception rooms and the heaviest to

* Communicated by the Director.

congested filing rooms equipped with wood filing cases stacked in heights of 8 to 10 feet. Any combustible material in finish floor and trim was included.

Following the standardization of fire testing procedure, beginning under the auspices of the American Society for Testing Materials in 1917, the results of fire tests conducted under controlled conditions indicated a large range in fire resistance of nearly comparable constructions and protections, resulting from variations in details of application, mineral composition of aggregates for concrete, and type of clay and hardness of burning for burnt clay products. Thus, steel columns protected with a 2-inch thickness of portland cement concrete supported a design load in the furnace test from less than two to over seven hours, and 8-inch clay hollow tile walls from less than two to over three hours as tested bare, and from less than three to over four hours with plaster on both sides. In view of this, in an attempt to make them more definite, the practice began of placing fire resistance requirements on the basis of performance in fire tests. The maximum requirements for buildings of the highest fire resistance or fireproof type were placed in the range $2\frac{1}{2}$ to 4 hours, generally without any allowance for different occupancies or combustible contents of the buildings.

In connection with the Government's low-cost housing activities, these building code and fire insurance requirements, while hardly obtaining the protection needed where large amounts of combustible contents are present, were found to be unduly restrictive as applied to residential occupancies. Where the kind and thickness of materials were specified, a fire resistance of over eight hours might be required for a hazard that would not correspond to more than the first hour of fire exposure in the standard furnace test. The Bureau was requested to coöperate in the development of reasonable recommended requirements, and in November 1938 a group was organized for this purpose, under the auspices of the Central Housing Committee, with representatives from the Home Owners' Loan Corporation, the Federal Housing Administration, the Public Buildings Administration, the Public Works Administration, the U. S. Housing Authority, and the National Bureau of Standards. Its work

has comprised classification and definition of building types from the standpoint of fire resistance, and surveys of combustible contents associated with representative occupancies or buildings. Surveys of school buildings, office buildings, dwellings and apartments, are completed or nearly completed, and surveys of warehouses and other commercial buildings are in progress. Work has also begun on compiling fire resistance classifications of building constructions and materials as based on published results of fire tests, and on acceptance tests or recent research, the results of which have not as yet been published.

During the past few months, the Bureau has conducted further fire severity tests under conditions more nearly representative of residential occupancies than those previously mentioned. A one-story building was outfitted as a living room, dining room kitchen suite, with furniture and other contents in the range $5\frac{1}{2}$ to $8\frac{1}{2}$ lb./ft.^{2} of floor area. Fires completely consuming these contents were indicated as equivalent in severity to from 30 to 45 minutes of the furnace test. In one test, representative of the maximum concentration of combustibles from furniture storage found in residential apartment buildings, the severity of the fire was indicated to be a little less than that for the first hour of the furnace test, the weight of combustible contents being equivalent to 12 lb./ft.^{2} over the whole floor area. This is in line with the results obtained in the previous fire severity tests with office occupancy.

INSPECTIONS OF COATINGS ON UNDERGROUND PIPE LINES.

The final inspections of the pipe-line coatings installed in 1930 in the tests undertaken jointly by coating manufacturers, the American Petroleum Institute, and the Bureau, will be made during the coming spring and summer. The work will be under the supervision of K. H. Logan, who will prepare the report, submit it to the coöperating coating manufacturers for criticism, and present it at the annual meeting of the Institute in 1940. A more complete and final report may be prepared later.

The following tests will be made: (1) soil resistivity measurements; (2) current on the working lines; (3) pattern tests for the location of pinholes; (4) coating resistance (electrical); (5) inspection of coatings, probably in accordance with the Underground Pipe Protection Institute's code for inspections; (6) measurements of pit depths on bare and coated specimens of pipe. Photographs of each coating will probably be taken, but only a few of them will be published.

At each of 13 test sites there remain 14 coatings on each of two 12-foot sections of working pipe line. At 15 test sites there are approximately 46 varieties of coatings applied to 2-foot sections of 3-inch pipe. There are also several sections of uncoated line and 3-inch pipe at each test site.

The exposure of this large number of protective coatings applied to working pipe lines, subjected to a variety of soil conditions for ten years, offers an unusual opportunity for the collection of information about the serviceability of protective coatings. At a recent meeting of the Topical Committee on Pipe Line Technology of the American Petroleum Institute it was decided to permit any one who so desires to be present at the time the coatings are exposed and to make such observations as he wishes, under three conditions: (1) That private observers will not delay the work or injure the coatings; (2) that the data obtained will be used only for scientific purposes; and (3) that the results of private inspections will not be published prior to the publication of the final report by the American Petroleum Institute.

Two organizations have already stated that they wish to have representatives accompany the Bureau's men from the beginning to the end of the inspection trip. These inspectors should be able to collect much more reliable and complete data than would be possible if different inspectors were sent to each site, and they will no doubt return with much information that could not be obtained through reading the published report.

The following is a tentative schedule for the inspections. Because of weather and labor conditions it may not be practicable to adhere strictly to the schedule, and it is impracticable to determine far in advance the exact day on which any particular coating will be exposed.

TENTATIVE SCHEDULE FOR INSPECTIONS OF PIPE COATINGS.

Site near	Inspection period
Long Beach, Calif.	March 4 to 12
Cholame Flats, Calif.[2]	March 14 to 20
Mendota, Calif.[3]	March 22 to 25
Temple, Tex.	April 2 to 10
League City, Tex.	April 12 to 20
El Vista, Tex.	April 22 to 30
Spindle Top, Tex.	May 1 to 9
Bunkie, La.	May 11 to 21
Council Hill, Okla.	May 24 to June 1
Skiatook, Okla.	June 3 to 11
Arkansas City, Kansas	June 13 to 21
Caney, Kansas	June 23 to July 2
Mt. Auburn, Ill.	July 5 to 13
Preble, Ind.	July 15 to 23
Chambersburg, Pa.	July 26 to Aug. 3

[2] Partial set of line coatings.
[3] Thirty-six coatings on 3-inch pipe only.

Any one who desires to have a representative at any or all of the test sites should send in his name and address to K. H. Logan, National Bureau of Standards, Washington, D. C., with a statement of the test sites he wishes to visit and the coatings in which he is especially interested.

FUEL REQUIREMENTS OF 1939 AUTOMOBILES.

In 1936 the Coöperative Fuel Research Committee initiated an annual survey to determine the fuel quality requirements of modern automobiles with respect to vapor lock and knock.

The fourth annual report, prepared at the Bureau and presented by Donald B. Brooks of the Automotive Power Plants Section at the winter meeting of the Society of Automotive Engineers in Detroit on January 18, shows that the octane number of fuel required to operate 1939 automobiles without knock is slightly higher than that found for 1938 cars. Many cars as run on the road require a higher than normal

grade of fuel to suppress knock because of improper adjustment of the spark advance mechanism. In two cases out of three, readjustment reduced the fuel requirement by about the difference between premium and regular grade gasoline. Scraping carbon made an even greater difference in 9 cases out of 10.

Half of the 1939 automobiles tested would operate satisfactorily on regular grade gasoline, but a small percentage would knock even on premium fuel. In regard to vapor lock, half of these cars would operate satisfactorily at an air temperature of 100° F. on a gasoline having a Reid vapor pressure of 9 lb./in.^{2}. One in eight, however, would require an 8-lb. fuel, and one in twenty a 7-lb. gasoline.

FIRST SPECTRUM OF TIN.

In the *Journal of Research* for February (RP1275) William F. Meggers reports the remeasurement with increased precision of all the lines of the tin spectrum observable photographically from the extreme ultraviolet to the infrared, and the correction of 37 lines of still greater wave-length, observed radiometrically. The total number of lines is 378 and the longest observed wave-length is nearly 15 times the shortest. A large majority of these tin lines are classified as combinations of identified atomic energy states, and from law-abiding series of such states the energy of binding of a valence electron in a tin atom is calculated. It is found that a free electron falling through a potential difference of 7.297 volts will acquire just enough energy to remove, upon collision with a normal tin atom, one of its valence electrons.

SAFETY RULES FOR RADIO INSTALLATIONS.

Handbook H35, "Safety Rules for Radio Installations," which was released in January, comprises part 5 (sections 50 to 59, inclusive) of the fifth edition of the National Electrical Safety Code. Certain definitions in section 1 of the code, which apply to the radio field, have also been included.

The various sections of the Handbook cover the classification of radio stations, antenna and counterpoise installation,

lead-in conductors, construction at building entrance, protective devices, protective and operating grounding conductors, grounds and ground connections, connections to power supply lines, and batteries.

Copies of H35 are obtainable from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 10 cents each.

The Combustion Gas Turbine.—DR. J. T. RETALIATA in Bulletin No. 4 of the Allis-Chalmers Manufacturing Company, Milwaukee, Wisconsin, deals with the development and theory of the gas turbine, as well as the features which make it appear as possessing attractive potentialities for certain classes of service. At the present time the continuous combustion gas turbine development is being carefully investigated by Allis-Chalmers. Five gas turbine-axial compressor units have been constructed to the designs of Brown-Boveri. Field experience with these machines should provide basic data for the future application of this power cycle. The advantages associated with the elimination of the high pressure, high temperature steam boiler and the attendant feedwater problems from a power plant are obvious. There is on the other hand a lack of experience with certain features of the development and further experience is necessary in connection with the effect of high oxygen content gas on blading materials at temperatures around 1000° F. and other matters. There is also the problem of reliable control of the combustion to prevent gas of excessive temperature reaching the turbine blading. The destiny of the steam turbine is not being decided by the gas turbine nor is its future even slightly jeopardized. The gas turbine must develop approximately four times as much energy as that which it delivers as excess, so its bid as a serious competitor to large steam turbines would require considerable development due to physical limitations. In moderate sizes, however, it will become an aspirant in the power field when higher operating temperatures are permitted by improved methods of blade cooling and materials with better creep and other high temperature properties.

R. H. O.

THE FRANKLIN INSTITUTE

STATED MONTHLY MEETING, FEBRUARY 21, 1940.

The regular monthly meeting of the Institute was held this evening at 8:15 o'clock with Dr. Henry Butler Allen, Secretary and Director, in the chair.

The minutes of the previous meeting were approved as published in the February issue of the Journal.

The additions to membership since last report were as follows:

Active	7
Associate	8
Student	30
Total	45

There being no further business the Chairman introduced Mr. Lawford H. Fry, Railway Engineer, Edgewater Steel Company, Pitstburgh, Pennsylvania, who presented a paper on The Steam Locomotive; its development and present position in railroad transportation. The lineage of the modern steam locomotive was traced back to Stephenson's "Planet." Transfer of the strain to America Stephenson to Stevens to Baldwin, was noted as well as the subsequent growth in size, complexity and efficiency. The vital principles of the steam locomotive and some methods of analysis were examined. Comparison was made with the competitive Diesel and electric locomotives, and a hesitant glance was cast toward the future.

The subject was illustrated by a series of lantern slides.

After a brief discussion a rising vote of thanks was extended to the speaker.

Adjourned.

HENRY BUTLER ALLEN,
Secretary.

LIBRARY NOTES.

The committee on Library desires to add to the collections of the Institute any technical writings of members who have had occasion to publish such material.

Literary contributions from author-members will be gratefully acknowledged, properly inscribed and noted in the Journal of the Institute.

Photostat Service. Photostat prints of any material in the collections can be supplied on request. Orders received in the morning are filled the same day. The average cost for a print 8½ × 11 inches is forty cents.

The library and reading room are open on Mondays, Tuesdays, Fridays and Saturdays from nine o'clock A.M. until five o'clock P.M., Wednesdays and Thursdays two until ten o'clock P.M. 874 readers made use of the facilities during the twenty-six days of January.

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NOTES FROM THE BARTOL RESEARCH FOUNDATION.

CONCERNING THERMIONIC REGULATION OF D.C. GENERATORS.*

BY

W. E. DANFORTH.

This paper presents a theoretical treatment of a type [1, 2] of thermionic regulator. The method enables one to appraise quantitatively the importance of any possible source of instability in amplifier or generator.

It is convenient to think of the device as a *voltage regulator* in conjunction with an auxiliary *current regulator* which, in order to compensate for certain gradual changes in the system, is continually re-adjusting the voltage at which the voltage regulator is set. Therefore we begin with the voltage regulating feature.

When an increase of the output voltage of the main generator occurs, the grid of the 6C6 tube is made more negative, thereby decreasing the field excitation with consequent decrease of the output voltage nearly to its original value. The following expression shows the extent to which the corrective action occurs.

$$\frac{dE}{E} = \frac{i}{1 - E\dfrac{\partial i}{\partial E}}\left[\frac{dK}{K} + \frac{1}{i}\frac{\partial i}{\partial x}\,dx\right].$$

The quantity dE/E is the fractional fluctuation of generator output voltage. The quantity preceding the bracket we call the *voltage regulation constant* and is the number (less than unity) by which the unregulated fluctuations are multiplied in order to calculate the regulated fluctuations. Since, in practice, the second term in the denominator is negative

* Condensed from a paper published in full in the *Reviews of Scientific Instruments*, **10**, 211 (1939).

[1] Gulliksen and Vedder, "Industrial Electronics," (John Wiley, 1935).

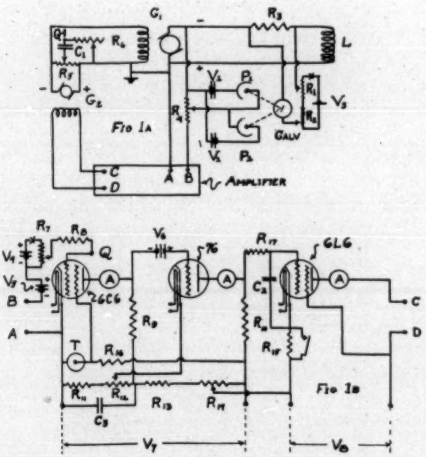
[2] Anderson, Dunning and Mitchell, *Rev. Sci. Inst.*, **8**, 497 (1937).

and large compared to unity, one has

$$\text{Voltage Regulation Constant} = \frac{E}{i}\frac{\partial i}{\partial E}.$$

The letter K is the constant of proportionality between the output voltage of the main generator and the field current of the exciting generator. The function i is the field current of the exciting generator. The quantity x is any quantity whose variation causes a change of amplifier output. Thus

FIG. 1.



Circuit diagram for regulation of voltage of a d.c. generator by means of a thermionic amplifier
The cyclotron magnet is represented by the inductance L. Numerical data are as follows:

R_1 = 10 ohms.
R_2 = 300 ohms.
R_3 = 0.007 ohm.
R_4 = 2 megohms.
R_5 = 600 ohms.
R_6 = 50,000 ohms.
R_7 = 20,000 ohms.
R_8 = 0.1 megohm.
R_9 = 0.1 megohm.
R_{10} = 25,000 ohms.
R_{11} = 3500 ohms.
R_{12} = 5000 ohms.
R_{13} = 3500 ohms.
R_{14} = 5000 ohms.
R_{15} = 700 ohms.
R_{16} = 10,000 ohms.
R_{17} = 0.1 megohm.
Main generator, output current = 170 amperes.
Main generator, output voltage = 75 volts.
Main generator field current = 1 ampere.
Exciter generator, output voltage = 67 volts.
Exciter generator, field current = 0.1 ampere.
C_1 = 8 microfarads, paper.
C_2 = 0.06 microfarad, paper.
C_3 = 8 microfarads, electrolytic.
V_1 = 90 volts.
V_2 = 90 volts.
V_3 = 1.5 volts (one No. 6 dry cells).
V_4 = 3.0 volts (two No. 6 dry cells).
V_5 = about 75 volts adjustable.
V_6 = about 35 volts adjustable.
V_7 = 250 volts, rectified a.c.
V_8 = 250 volts, rectified a.c.
P_1 and P_2 = RCA cartridge photocells, type 922.
T = type 874 gas-discharge regulator, 90 volt drop.

the first term within the brackets represents the unregulated change of voltage arising from changes occurring in either the main generator of the exciter. The second term takes account of changes occurring in the amplifier. The action of the regulator diminishes both of these disturbances by the same factor.

Now considering the current control feature we follow the same procedure as we have in the case of the voltage regulator and arrive at the following expression for that number by which the unregulated current fluctuations are multiplied.

$$\text{Current Regulation Constant} = \frac{I}{R_3}\frac{\partial e}{\partial I}.$$

In this formula I is the output current of the main generator, R_3 is the resistance across which the balanced galvanometer circuit is connected, and ∂e represents a voltage change occurring in the galvanometer circuit under conditions of no feed-back, i.e. with R_3 not included in the galvanometer circuit. Again, the fluctuations by which the regulation constant is multiplied in order to calculate the final degree of constancy are not only those in the unregulated generator but include all such variables as photocell sensitivity, galvanometer sensitivity, amplifier sensitivity, etc.

For details of the derivations of the above formula, and for a technical discussion of the equipment shown in the diagram, the reader is referred to the original paper.

This equipment was developed for use with the cyclotron of the Biochemical Research Foundation.

THE EAST-WEST SYMMETRY OF THE COSMIC RADIATION AT VERY HIGH ELEVATIONS NEAR THE EQUATOR AND EVIDENCE THAT PROTONS CONSTITUTE THE PRIMARY PARTICLES OF THE HARD COMPONENT.*

BY

THOMAS H. JOHNSON AND J. GRIFFITHS BARRY.

The east-west symmetry of the soft component of the cosmic radiation has been investigated near the equator by

* An abstract of a paper published in full in the *Physical Review*, **56**, 219 (1939).

sending triple coincidence counters into the stratosphere with free balloons. The data were transmitted to a ground station by radio signals. Direct comparisons between eastern and western intensities were made on flights in which the orientation of the instrument was determined by means of a photocell actuated by light from the sun. On other flights we have studied the fluctuations which would be introduced into the counting rates by the rotation of the balloon if the radiation were asymmetric. The results show that the asymmetry is less than about seven per cent., a value far below what would have been expected if all of the primary radiation were positive. Analysis shows that less than about ten per cent. of the intensity at a depth of one meter of water is attributable to unbalanced positives. Contrasting this result with that found from the asymmetry at sea level that the mesotrons of the hard component are produced entirely by positive primaries, it becomes necessary to conclude that the mesotrons are produced in the upper atmosphere, not by the primary electrons of the soft component, but by an independent primary component consisting probably of protons or some other more massive positive ion. Reasons based upon the electrical properties of space are advanced to show that it is reasonable to expect to find protons of high energy in the primary cosmic radiation.

THE ANGULAR DISPERSION OF THE COSMIC RADIATION IN THE UPPER ATMOSPHERE RESULTING FROM DEFLECTIONS OF LOW ENERGY PARTICLES IN THE EARTH'S MAGNETIC FIELD.*

BY

T. H. JOHNSON.

In order to estimate the diffuseness of the soft component of the cosmic radiation with respect to the direction of the primary particles for the interpretation of east-west asymmetry measurements a calculation has been made of the angular spread of secondary rays produced by deflections in the earth's magnetic field for the idealized case where the primary particles are incident unidirectionally from the ver-

* An abstract of a paper published in full in the *Physical Review*, **56**, 226 (1939).

tical. Both radiation and ionization losses have been considered and it is found that at a depth of one meter of water rays whose energies exceed 15 Mev. lie within thirty degrees and half of the intensity is within five degrees of the original direction. The beam broadens at higher elevations or when lower energies are included. The correction to the recent east-west asymmetry measurements at very high elevations because of this effect is wholly negligible.

SHOWERS PRODUCED BY PENETRATING RAYS.*

BY

W. F. G. SWANN AND W. E. RAMSEY.

For investigating showers we have used an apparatus involving the following: At the top there is a block of lead 20 cm. square and 18 cm. thick. Below this, and separated by spaces so as to cover a total length of 140 cm., there are four slabs of lead each 1 cm. thick. Above the thick lead block, and at suitable distances above each of the other blocks, and beneath the lowest are trays, each containing 18 Geiger counters placed side by side. The counters are 1 cm. in diameter and 20 cm. long. Each is connected to an individual electroscope. The nature of the electrical arrangements is such that no electroscope is allowed to deflect unless at least one ray—and so a penetrating ray—has passed through all of the trays. Under these conditions, however, every counter which discharges is caused to record such discharge by means of a process in which spots of light reflected from the mirrors of all of the electroscopes are photographed.

We have used the above apparatus, among other studies, for the determination of the number of events which are accompanied by n additional rays for a range of n from 1 to 8. Results of two sets of experiments [1] are recorded in Table I

* Reprinted from the *Physical Review*, 56, 378 (1939).

[1] These two experiments differ in the fact that in the first there was a single 1-cm. block of lead in addition to the 18-cm. block, while in the second experiment there were four 1-cm. blocks in addition to the 18-cm. block. Moreover, in the second experiment certain precautions were taken to eliminate the effect of electron showers coming in from the side and operating the apparatus.

together with the theoretical data given by H. J. Bhabha's [2] theory. In this table, E refers to the energy of a mesotron and m to its rest mass.

The final averages given at the bottom of the table are corrected for counter inefficiency. It will be seen that these results agree very well with Bhabha's theory as regards the relative number of rays for mesotron energies between 10^{10}

TABLE I.

Number of Events Which Are Accompanied by n Additional Rays. E is the Mesotron Energy, m Its Rest Mass.

Theoretical.

$E - mc^2$.	$n = 1$.	2.	3.	4.	5.	6.	7.	8.
10^8 ev.	13.6	2.3	1.5	0.8	—	—	—	—
10^{10}	26.0	8.0	5.6	3.2	2.1	0.7	—	—
10^{12}	26.0	8.5	6.0	3.4	2.3	0.8	—	—

Experimental.

Exp.	Thickness of Pb.	$n = 1$.	2.	3.	4.	5.	6.	7.	8.
1.	Below 18 cm. Pb	11	5	1	2	1	1	1	1
	Below 19 cm. Pb	13	4	3	0	3	0	0	0
2.	Below 18 cm. Pb	7	3	0	0	0	1		
	Below 19 cm. Pb	10	4	1	1	0	0		
	Below 20 cm. Pb	12	2	1	0	0	0		
	Below 21 cm. Pb	11	2	1	1	0	0		
	Below 22 cm. Pb	9	1	0	1	0	0		
Averages for all data		10	3	1	0.7	0.6	0.3		
Final corrected averages		12.5	5	2	1.7	1.8	1.2		

ev. and 10^{12} ev. The actual number of rays found experimentally is about half that given by the theory and is more in accord with mesotron energies of 10^8 ev.

A complete description of these experiments and of other results from them will be published in a paper entitled "Showers Produced by Penetrating Rays and Allied Phenomena" by W. F. G. Swann, given as part of the "Symposium on Cosmic Rays" held at the University of Chicago, June 27–30, 1939.

[2] H. J. Bhabha, *Proc. Roy. Soc.*, **164**, 257 (1938).

THE EFFICIENCY OF DIFFERENTLY DESIGNED TUBES FOR THE THERMAL SEPARATION OF GASES AND ISOTOPES.

BY

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The problem of improving the efficiency in the thermal separator can be investigated by two general methods of attack. First, it might be possible by the use of suitable screens and baffles to enhance the efficiency of the conventional vertical concentric tube separator;[1] also differently designed separation apparatuses may be devised which give a greater yield per unit power imput.

A study of models of this character has the additional advantage of aiding in the interpretation of the mechanism which produces the separation.

MODEL 1.

In one case, the central cylinder of an apparatus constructed with two concentric cylinders was wound on the outside with 16 gauge nickel wire used as a baffle. For two different apparatuses with 7 mm. and 10 mm. wall clearance respectively each 1 m. long, the separation factor was increased as much as 40 per cent. by spacing the pitch of the windings so that the distance between two neighboring turns was of the same order as the wall clearance. The mass speed was not materially different from that for the same apparatus without the wire spiral wound on the central column. The characteristics of this design, such as concentration as a function of the time, correspond to that for a simple concentric cylinder apparatus with a length 40 per cent. greater than the wire wound model.

MODEL 2.

It is also of interest to find out how a perforated brass cylinder 1 mm. thick, extending the full length of the tube and placed concentircally between the hot and cold cylinders, midway between them, can affect the separation factor. For

* Guest Fellow of Bartol Research Foundation of the Franklin Institute.

[1] A. Bramley and A. K. Brewer, *J. Phys. Chem.*, **7**, 553 (1939).

the concentric cylinder apparatus with 7 mm. wall clearance and 1 m. length, the separation factor varied linearly with the ratio of the area of the holes to the total area of the brass cylinder as closely as we could observe with different brass cylinders whose walls were from 40 to 80 per cent. perforated. In order to increase the accuracy of these measurements, a 50–50 mixture of CO_2 and N_2 at 22 cm. pressure was used. Without the perforated brass cylinder, the separation factor was 3.0; with a perforated brass cylinder of 40 per cent. perforation, the separation factor decreased to 1.8, while with a solid cylinder in the identical position as the perforated brass cylinder, the separation factor decreased further to 1.2.

MODEL 3.

In another modification of the vertical concentric tube design similar to the one investigated by Clausius and Dickel,[2] with a 7 mm. wall clearance, perforated discs were placed in the gas chamber in 3 different experiments on 1 m. tubes every 20, 6 and 3 cm. apart respectively. These discs, 40 per cent. of whose area was perforated with 0.25 cm. holes, fitted tightly between the inner and outer cylinders. The separation factor for an initial 50–50 mixture of N_2 and CO_2 at 22 cm. pressure was 3.2 and was independent of the distance between the discs. The same apparatus, without the discs, gave a separation factor of 3.0.

MODEL 4.

As we have mentioned in a previous publication—*Science*, August 18, 1939—inclining the concentric cylinder apparatus as much as 20° from the vertical destroys the efficiency of the apparatus. This is not true, however, for the parallel plate apparatus which we have recently investigated in detail. With a 15 mm. I.D. glass tube, 1 m. long, heated with a 4 mm. Pt. ribbon on the upper inside surface and water cooled on the lower outside surface, the separation factor for an initial 50–50 mixture of CO_2 and N_2 at 22 cm. pressure remained constant, within the experimental error of ± 0.05, at the value 1.3 as the tube changed its angle of inclination from the vertical from 15° to 75°. However, at a gas pressure of 40

[2] K. Clausius and G. Dickel, *Zeits. f. phys. Chemie*, **B, 44**, 451 (1939).

cm. the separation factor of 1.5 decreased to nearly zero as the inclination changed from its initial slope of 75° to 45°. With a power imput of 30 watts, 22 cc. of gas at N.T.P. could be withdrawn per hour without changing the separation factor appreciably.

When the brass strip was placed midway between the heated Pt. strip at the top side of the tube and the water cooled lower side of the inclined parallel plate apparatus, no separation could be detected. However, when 40 per cent. of the area of the strip was perforated the separation factor rose to its original value of 1.3. This comparison was performed at 22 cm. pressure.

A reasonable interpretation of these results is that in the inclined parallel plate apparatus there exists one swirl (convection stream up the hot wall and down the cold wall) in which the hot and cold streams flow into each other at the ends of the tube, whereas in the vertical concentric cylinder apparatus, there can be a number of swirls along the length of the gas chamber. These hot and cold streams must mingle at more places than the ends of the tube. For example, in the experimental arrangement described in the last paragraph of page 2, a mixing of streams must occur at the baffles; in this case, then, the length of the swirls cannot be longer than the distance between neighboring discs which were in these different experiments 20, 6 and 3 cm. apart respectively.

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NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION.

The Specific Volume Factor in Ultracentrifugal Analysis.—E. O. KRAEMER. (Abstract of contribution to the conference on "Crystalline Protein Molecules" held under the auspices of the New York Academy of Sciences, February 2–3, 1940.) In considering the reliability of molecular weights determined by ultracentrifugal methods, attention must be given the specific volume factor $(1 - V_1\rho)$, in which V_1 represents the partial specific volume of component 1 whose molecular weight is to be calculated and ρ is the density of the solution, both quantities having the values as they exist in the cell under the particular conditions of centrifuging. For a dilute, ideal solution in which no combination occurs between component 1 and other components of the solution, and the effects of electric charge, if any, are properly repressed, the equations for molecular weight by sedimentation equilibrium and by sedimentation velocity are valid, regardless of the size or shape of the molecule. If it is desired to obtain molecular weights with an error not exceeding 1–2 per cent., and if the conditions of experimentation are otherwise favorable, the error in $(1 - V_1\rho)$ should not exceed 0.5 per cent. For proteins in aqueous solutions V_1 is about 0.75 and $(1 - V_1\rho)$ is about 0.25; therefore the error in V_1 and in ρ should in such cases not exceed 0.2 per cent. In sedimentation equilibrium measurements with proteins, the corrections for the greater hydrostatic pressure in the centrifuge cell are negligible, but for the most precise sedimentation velocity determinations at high speeds, corrections should be applied in accordance with the discussion of Svedberg and Pedersen ("The Ultracentrifuge," Oxford University Press, London, 1940).

The determination of the density of the solution within the specified error presents no particular difficulty, but the measurement of the partial specific volume of a protein (or other high polymer) to this accuracy for the dilute solutions required for molecular weight determinations (usually less

than 1 per cent.) is by no means easy. Thus, for an error of 0.2 per cent. in a 0.5 per cent. solution, the relative weights of solution and solvent must be correct to 1 in 100,000; this demands accurate temperature control, the application of buoyancy corrections, and the use of fairly large pycnometers. In addition, considerable pains are necessary to define the absolute concentration to 0.1–0.2 per cent. Whenever, for any reason, $(1 - V_1\rho)$ is appreciably less than 0.25, the accuracy of the molecular weight values inevitably suffers.

In the event that component 1 combines with some other component of the solution (by either "solvation" or combination with salts) an error arises in the molecular weight because of the change in the partial specific volume of the sedimenting component. If the partial specific volume of the resulting compound were known, the use of this value would give the molecular weight of the compound. However, it is usually the molecular weight of the uncombined macromolecular solute that is desired. The error resulting from the use of the partial specific volume of the uncombined high polymer in the calculation of the molecular weight may be shown to be given by the equation

$$M_1 = \frac{M_1^a(1 - V_1\rho)}{(1 - V_1\rho) + \Sigma r_i(1 - V_i\rho)}, \tag{1}$$

where M_1 is the true molecular weight for the uncombined molecule (component 1), M_1^a is the apparent molecular weight obtained by the conventional calculation, V_1 is the partial specific volume of the high polymer, referred to the uncombined state, and r_i is the weight in grams of component i with partial specific volume V_i combined with 1 gram of component 1. The partial specific volume of the high polymer compound V_c becomes

$$V_c = \frac{V_1 + \Sigma r_i V_i}{1 + \Sigma r_i}. \tag{2}$$

Incidentally, these equations express the error due to combination for sedimentation velocity (with diffusion) as well as for sedimentation equilibrium.

For a simple binary solution (in which combination is

commonly termed solvation), the above equation reduces to

$$M_1 = \frac{M_1^a(1 - w_1)}{1 - w_1 - rw_1}, \tag{3}$$

where w_1 is the weight fraction concentration of the high polymer in the solution. Since for a concentration of 0.5 per cent., a solvation of 200 per cent. causes an error of only 1 per cent. in the molecular weight, and molecular weight determinations may normally be carried to still lower concentrations, the error from solvation is usually negligible in binary solutions. However, the molecular weights of proteins are rarely if ever measured by ultracentrifugal methods in binary solutions, and equation (1) must be used to estimate the error due to solvation or combination. Inasmuch as the partial specific volume of water is nearly equal to the density of the usual buffer solutions used, the factor $(1 - V_i\rho)$ for water does not commonly exceed 0.01, and in such cases, therefore, a 50 per cent. solvation (which is the order of magnitude of the solvation possibly occurring in protein solutions) would lead to an error in molecular weight of only 2 per cent. The factors $(1 - V_i\rho)$ for the electrolytes present would be larger than that for water, but on the other hand, the values of r_i would undoubtedly be rather small, especially near the isoelectric point (possibly rarely as great as 0.1), and the error from this cause would be correspondingly small.

Unfortunately, the exact values of the corrections for combination of the macromolecular substance with components of the solution usually cannot be calculated because the values of r_i are unknown; neither can the molecular weight of the compound be determined. It is true that McBain (*J. Am. Chem. Soc.*, **58**, 315, 1936) has suggested that the partial specific volume of the *compound* (or "solvate," as the case may be) can be determined by adjusting the density of the solution until its specific volume is equal to the partial specific volume of the compound, whereupon no sedimentation would occur. For proteins, however, the elimination of sedimentation (judging from densities of protein crystals observed by Adair, *Proc. Roy. Soc. London*, **120B**, 422, 1936) would require such high salt concentrations as certainly to

reduce greatly the solvation of the protein, besides possibly leading to other profound changes in the protein. This is therefore not a promising method for estimating the degree of solvation of proteins in the usual types of solutions.

The frictional resistance of a molecule, as it settles in a centrifugal field or diffuses freely in a solution, is modified by solvation owing to increase in the size of the kinetic unit and change in its partial specific volume. The frictional ratio (see Svedberg and Pedersen, "The Ultracentrifuge") is thereby increased by the factor

$$(4) \qquad f_s/f_0 = \frac{1 - V_1\rho}{1 - V_1\rho + r(1 - V_2\rho)}\left(\frac{rV_2 + V_1}{V_1}\right)^{\frac{1}{3}}$$

for sedimentation velocity, and by the factor

$$(5) \qquad f_D/f_0 = \left(\frac{rV_2 + V_1}{V_1}\right)^{\frac{1}{3}}$$

for diffusion, where f_0 is the friction of a spherical, unsolvated molecule of the same volume as the macromolecule in question, and V_2 is the partial specific volume of the solvent. For a protein a hydration of 50 per cent. corresponds to a frictional ratio of 1.2, so it seems conceivable that the many proteins with frictional ratios of this order of magnitude are hydrated, substantially spherical molecules (cf. Adair, *ibid.*). In the absence of solvation, non-spherical form also gives a frictional ratio greater than unity; thus a value of 1.2 corresponds (according to the equations of Perrin, *J. Phys. Rad.*, VII, 7, 1, 1936) to an ellipsoid with an axial ratio of approximately 5. From ultracentrifugal studies alone, it is impossible to distinguish between solvation and non-spherical form as the cause for frictional ratios greater than unity. However, in the event that r calculated from the frictional ratio agrees with r calculated from viscosity measurements (where

$$(6) \qquad r = \frac{V_h - V_1}{V_2},$$

V_h being the specific hydrodynamic volume of the macro-

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molecule (Kraemer and Sears, *J. Rheol.*, **1**, 667, 1930), it may be permissible to assume that one is dealing with a solvated, spherical molecule. Observations of streaming birefringence (Sadron and Mosimann, *J. Phys. Rad.*, VII, **9**, 384, 1938) possibly provide a more reliable means of detecting non-spherical particles.

The Design and Construction of a Mercury Vapor Rectifier Tube.—A. J. ALLEN and A. G. NESTER. (*The Review of*

FIG. 1.

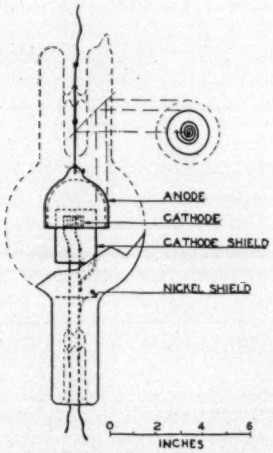

Diagram of mercury vapor rectifier tube.
(Courtesy Review Scientific Instruments.)

Scientific Instruments, **11**: 43, 1940.) A mercury vapor rectifier tube was developed for use in the oscillator plate supply of the Biochemical Research Foundation cyclotron. This tube proved to be satisfactory for the requirements placed on it by this type of operation. A diagram of the tube is shown in Fig. 1. The filament current is 40 amperes at 1.6 volts.

The tube described was operated in a three phase full-wave rectifier circuit delivering up to 4 amperes D.C. at 10 kilovolts. Smaller tubes have been made for lower power requirements.

The cathode is an oxide coated strip of nickel gauze placed in a cylindrical nickel shield. The anode is a cup-shaped piece of carbon. The glass envelope is made of Pyrex with Nonex-glass seals.

Evacuation of the tube is accomplished by attaching it in a baking-out furnace to a high vacuum apparatus; after thorough baking of the glass the filament is heated to outgas it. Mercury is then distilled into the tube and a D.C. current of 100 amperes passed through the tube for several hours until a high degree of evacuation is attained. All necessary dimensions and the complete details of construction and evacuation are given in the original paper.

(Abstracted by M. SAMPSON.)

The Reaction between Hydrogen Selenide, Formaldehyde, and Secondary Amines.—ARTHUR H. BINZ, FRANCIS E. REINHART and HARRY C. WINTER. (*Journal of the American Chemical Society*, **62**: 7, 1940.) The formation of substituted bis(aminomethyl) sulfides from secondary amines, formaldehyde, and hydrogen sulfide has been reported from this laboratory (Binz and Pence, *J. Am. Chem. Soc.*, **61**: 3134, 1939). The use of hydrogen selenide in place of hydrogen sulfide in this reaction has now resulted in the formation of analogous selenides which were desired for biological testing as possible chemotherapeutic agents. Bis(4-morpholylmethyl) selenide and bis(1-piperidylmethyl) selenide were obtained from morpholine and piperidine, respectively. Both compounds are crystalline but, unlike the corresponding sulfides, decompose easily under the combined influence of solvents and air with liberation of elementary selenium. When injected intravenously into rats, the lethal dose was of the order of 0.012–0.017 grams per kilogram of body weight.

Attempts to prepare similar selenides from dimethylamine and diethanolamine gave unstable oils which could not be purified.

BOOK REVIEWS.

THE PAGEANT OF ELECTRICITY, by Alfred P. Morgan. 363 pages, plates, illustrations, 15 × 23 cms. New York, D. Appleton-Century Company, 1939. Price $3.50.

This book is written in a biographical vein for popular consumption, tracing from the earliest observed manifestations of electricity the developments to the present time. In its sixteen chapters there are many glimpses into the lives of discoverers and contributors to electrical knowledge and these together with descriptions of their experiments and practical results make an interesting account. Generally, the fore part of the book is devoted to electric power and the latter part to communications. At places in both parts, the author seems a little overzealous in making his work broad and detailed for he enters into fields of economics, etc. Undoubtedly these had some bearing on the progress of electricity but it is questionable whether accuracy as to causes and motives can be recorded in a narrative such as this. There is distinctly recognized, in some instances, a looseness in dealing with facts which adds more to the reflection of doubt throughout the book.

The book is well illustrated with sketches and photographs and a feature is the chronology of important events. If it is read casually and the points not taken too seriously an interesting pastime can be had.

R. H. OPPERMANN.

MOLECULAR SPECTRA AND MOLECULAR STRUCTURE. I. DIATOMIC MOLECULES, by Gerhard Herzbert. 592 pages, illustrations, tables, 16 × 24 cms. New York, Prentice-Hall, Inc., 1939. Price $6.50.

This is a subject which has come into its own only comparatively recently and which has contributed to physical and chemical procedures in numerous ways. The study of the molecular spectra is one of the most important means for investigating molecular structure. To mention a few of the results there are the derivation of the energy states of a molecule, information on the motion of a molecule and the vibration and rotation of the nuclei in the molecule, an understanding of physical and chemical properties of gases, a prediction of chemical equilibria, and data on the physics of atomic nuclei. The consequent importance of the subject makes it imperative that a comprehensive and logical presentation be given for students.

As the title indicates, this volume deals only with the spectra of diatomic molecules and the conclusions which can be drawn from them concerning the structure of these molecules. A second volume, not yet published, will deal with polyatomic molecules according to the author. This first volume is a translation from German with certain additions in the way of recording more recent developments.

The presentation begins with a short survey of the fundamentals of atomic theory which furnishes a recollection of a basic necessity for what follows. In

order, there follow treatments on observed molecular spectra and their representation by empirical formulae, rotation and vibration of diatomic molecules, a discussion of electronic states and electronic transitions, electron configurations and valence, and continuous and diffuse molecular spectra. The last chapter is devoted to examples, results, and applications. There is an extensive bibliography in the back as well as an author and subject index, the latter containing symbols, quantum numbers, etc. The work is adequately illustrated and there are tables throughout giving pertinent data.

While much of the material herein presented is not new, the coverage, approach, and procedure of presentation merit a serious consideration of the book by students and research workers.

R. H. OPPERMANN.

THE HISTORY OF PHOTOGRAPHY, ITS RELATION TO CIVILIZATION AND PRACTICE, by Dr. Erich Stenger. Translation by Edward Epstean. 204 pages, plates, 16 × 24 cms. Easton, Mack Printing Company, 1939. Price $5.00.

Photography has a very useful function in the daily life of each one of us wherein a rapid assimilation of facts is necessary. The art and beauty available through photographs are only one of many phases of usefulness. "A picture is as good as a thousand words" has a great deal of truth in portraying news events, advertising, achievements in research and other purposes, to mention only a few, and not the least important is the quick and permanent impression on the mind left by photographs. As a matter of fact, the use of photography in education has promise of a bright future. The great sacrifices that were made, the innumerable difficulties that had to be overcome, and the contribution of scientific knowledge to make possible this asset to mankind can only be appreciated by those who know something of the history of photography. The book at hand attempts to fill this need. As stated it is a translation by Edward Epstean of the original in German by Dr. Erich Stenger.

It begins with a general history of the origin of photography, from the time of Johann Heinrich Schulze in 1727, and then proceeds through sections on photographic apparatus, applied photography, and photography as a profession, a hobby, and as an economic asset. After this there is a very interesting exposition of utterances by people of note on their speculations as to the future and value of photography as they saw it in their day. These quotations are arranged chronologically from 1838 to modern times.

The author has conveniently arranged the work into short sub-sections, some 165 in all. This has the effect of shortening the narrative somewhat, but brings forth matter-of-fact and concise points, definitely limited in scope. The sub-sections are neatly bridged, one to the other, so that logical progression results. The brevity which is apparent is a minor drawback, which is in favor of completeness in coverage at the expense of more detailed descriptions of items of major importance. The good subject index makes the book especially valuable as a reference. The book can be recommended to photographers of all descriptions and degrees, and even those not directly interested in the technique of photography will find much of a useful informative character.

R. H. OPPERMANN.

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ELEKTRISCHE HÖCHSTSPANNUNGEN, von A. Bouwers. 333 pages, illustrations, 17 × 25 cms. Berlin, Julius Springer, 1939. Price 31.20 R.M.

The use of high tension electric current of various types is increasing for both research as well as practical testing. This is so to the extent that developments along these lines have come to the point that the field is one of more or less specialized knowledge. The book at hand contains a resumé of modern developments in the different methods of production and use of voltages of the order of several hundred thousand volts. Written in German, its technical descriptions are quite complete with discussions on the electric field, insulation, and the various apparatus that go to make up high tension generating equipment and their function. There are also reviewed applications in power transmission, materials testing, radioactivity, etc. The measurement of high voltages, the production of Röntgen and cathode rays, and utilization for physical investigations are covered.

The book is profusely illustrated with photographs, curves and figures. In the back there is a bibliography of 324 references and a comprehensive subject index. For those who can read German this work will provide a convenient summary that gives the essentials in theory.

R. H. OPPERMANN.

DER DISPERSE BAU DER FESTEN SYSTEME, ALLGEMEINE THEORIE DER VERUNREINIGUNG FESTER SYSTEME, von Prof. Dr. D. Balarew. 240 pages, illustrations, 16 × 24 cms. Dresden, Theodor Steinkopff, 1939. Price 8.62 R.M.

The subject as it is discussed here is fundamental or introductory through demonstration and performance, and is the result of an exhaustive gathering of material from widely different sources and an intensive study of the structure of certain crystal systems. The basis of the theory is covered broadly from which there is evolved interlocking or netlike conceptions of formations of salt systems. The author makes reference to experimental methods which give like results, and by use of the same theory, examinations are made where the appearance of a system differs, employing different physical-chemical properties or effects to support the correctness of fundamental ideas. Critical inspection is made of the work of others and there is no hesitancy in pointing out the previous limitations of experimental method with relation to the soundness of the theory here given. However, due credit and weight are given. The presentation progresses evenly by development of theory and application in experiments toward important practical results. In particular, one instance of this is worthy of mention, that is where there is given methods for the production of a pure salt system. Here interest should cover the analytical field as well as the production of inorganic chemicals. The work, written in German, should be given attention by those qualified by an understanding of the language and by scientific knowledge.

R. H. OPPERMANN.

BLÄTTER FÜR TECHNIKGESCHICHTE, SECHSTES HEFT. SCHRIFTLEITUNG: Dr. Ing. L. Erhard. 82 pages, illustrations, 18 × 25 cms. Berlin, Julius Springer, 1939. Price 4 R.M.

Mention has been made before in these columns about the series of booklet narratives on technical contributions and achievements in countries now included

in the German Reich. This booklet belongs to this series which is published by the Forschungsinstitut für Tcchnikgeschichte in Wien. The introduction by Hofrat Dr.-Ing. L. Erhard gives in an interesting manner a broad description of the progress made in technical science and workmanship of the people which has been the result of pressing needs, ambition, ingenuity and thrift. Following this Dipl.-Ing. Otto Lanser discusses the development and construction of old bridges and mills throughout the countryside of Tirol. There is much of interest in the way of structural details which are described and illustrated. Road construction through various parts of Austria and Tirol covering 70 years is the topic of Dipl.-Ing. F. Kargl. Illustrations and cross sections of tunnels showing the materials of construction in some of the mountainous sections are of note.

R. H. OPPERMANN.

TIDES IN THE AFFAIRS OF MEN, by Edgar Lawrence Smith. 178 pages, illustrations, 15 × 22 cms. New York, The Macmillan Company, 1939. Price $2.00.

There is much evidence these days of the progress of knowledge along certain definite lines being assisted by contributions of knowledge from other entirely different fields of endeavor. To correlate knowledge in this way especially when there is only a hint of possible agreement and results is a task of no small magnitude. It is a work replete in true research with all of its necessities of ingeniousness and patience.

This book offers a possible groundwork in the realm of economics, a field that is rapidly becoming recognized as a science along with the better known subjects of science, and which has heretofore been known to many as the "dismal science." The author seeks to bring together the changes of business prosperity and changes due to nature such as atmospheric and other conditions. There are two parts to the book, the first entitled, "The Decennial Pattern and Other Periodicities" dealing with biological cycles and stock price movements, tides in mass psychology, the weather, and others. In part two the development of the decennial pattern in stock price movements so far developed is used as a background for exploration in natural phenomena. This, according to the author, appears also to follow a decennial pattern and an attempt is made to discover whether or not divergencies from normal in the latter may be relied upon to warn us of divergencies to be expected in the former.

The basis of attack on the problem is the use of cyclic changes which occur, it is claimed, in both natural phenomena and in man's dealings and relationships. This is not the first time that thoughts have run in this direction as witness the familiar statements concerning predictions of the effects of sun spots on man's activities. Also to stretch a point one might refer to the predictions from astrology. But this is no reason to dismiss a book like "Tides in the Affairs of Men." There is very definitely no harm done in presenting an opinion. As a matter of fact the author brings forth some very interesting revelations and while he makes no claim as to completeness of conclusions, there is pointed out a direction for further studies which may be pursued. The book will at least set the reader's mind to work.

R. H. OPPERMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 674, Cooling on the Front of an Air-Cooled Engine Cylinder in a Conventional Engine Cowling, by M. J. Brevoort and U. T. Joyner. 13 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1939. Price 10 cents.

Measurements were made of the cooling on the fronts of model cylinders in a conventional cowling for cooling in both the ground and the cruising conditions. The mechanisms of front and rear cooling are essentially different. Cooling on the rear baffled part of the cylinders continually increases with increasing fin width.

For the front of the cylinder, an optimum fin width was found to exist beyond which an increase in width reduced the heat transfer.

The heat-transfer coefficient on the front of the cylinders was larger on the side of the cylinder facing the propeller swirl than on the opposite side. This effect became more pronounced as the fin width was increased. These results are introductory to the study of front cooling and show the general effect of the several test parameters.

Report No. 675, Effects of Elevator Nose Shape, Gap, Balance, and Tabs on the Aerodynamic Characteristics of a Horizontal Tail Surface, by Harry J. Goett and J. P. Reeder. 11 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1939. Price 10 cents.

Results are presented showing the effects of gap, elevator nose shape, balance, cut-out, and tabs on the aerodynamic characteristics of a horizontal tail surface tested in the N. A. C. A. full-scale tunnel.

The presence of a gap caused an 18 per cent. reduction in the variation of normal force with elevator deflection but the size of the gap (between 0.005c and 0.010c) was an unimportant factor. At small elevator deflections, the effectiveness of aerodynamic balance of the elevator in reducing hinge moments was much lower with the tapered nose than with the blunt nose. The tapered nose, however, maintained its effectiveness to much greater deflections and gave a greater maximum normal-force increment than did the blunt nose. With the blunt nose, the hinge moments were reduced 30 and 40 per cent. with 10- and 20-per cent. balances, respectively. This reduction is fairly uniform up to the stall of the elevator. The decrease in normal force and hinge moment caused by a cut-out was proportional to the area removed. The variation in tab effectiveness with a change in tab span was found to be approximately proportional to the area-moment of the tab about the elevator hinge line. A comparison of the various experimental aerodynamic characteristics with those computed from Glauert's thin-airfoil theory for hinged flaps is also given.

Report No. 678, Interference of Tail Surfaces and Wing and Fuselage from Tests of 17 Combinations in the N.A.C.A. Variable-Density Tunnel, by Albert Sherman. 10 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1939. Price 10 cents.

An investigation of the interference associated with tail surfaces added to wing-fuselage combinations was included in the interference program in progress in the N.A.C.A. variable-density tunnel. The results indicate that, in aerodynamically clean combinations, the increment of the high-speed drag can be

estimated from section characteristics within useful limits of accuracy. The interference appears mainly as effects on the downwash angle and as losses in the tail effectiveness and varies with the geometry of the combination. An interference burble, which markedly increases the glide-path angle and the stability in pitch before the actual stall, may be considered a means of obtaining satisfactory stalling characteristics for a complete combination.

PUBLICATIONS RECEIVED.

The Physical Examination of Metals, by Bruce Chalmers. Volume I, Optical Methods. 181 pages, illustrations, 15 × 22 cms. New York, Longmans, Green & Co., 1939. Price $4.00.

The Mathematical Theory of Non-Uniform Gases, by Sydney Chapman and T. G. Cowling. 404 pages, illustrations, 18 × 26 cms. New York, The Macmillan Company, 1939. Price $7.50.

Fundamentals of Physical Chemistry, by Earl C. H. Davies. Second Edition, 447 pages, illustrations, tables, 15 × 22 cms. Philadelphia, The Blakiston Company. Price $3.50.

Statistical Thermodynamics, by R. H. Fowler and E. A. Guggenheim. 693 pages, illustrations, tables, 19 × 27 cms. New York, The Macmillan Company, 1939. Price $9.50.

Mr. Tompkins in Wonderland, or *Stories of c, G, and h*, by G. Gamow. 91 pages, illustrations, 17 × 22 cms. New York, The Macmillan Company, 1940. Price $2.00.

M.K.S. Units and Dimensions and a Proposed M.K.O.S. System, by G. E. M. Jauncey and A. S. Langsdorf. 62 pages, illustrations, 15 × 22 cms. New York, The Macmillan Company, 1940. Price $1.00.

Mathematical Methods in Engineering, by Theodore v. Karman and Maurice A. Biot. 505 pages, illustrations, 16 × 24 cms. New York, McGraw-Hill Book Company, Inc., 1940. Price $4.00.

General Physics for Students of Science, by Robert Bruce Lindsay. 534 pages, tables, illustrations, 16 × 24 cms. New York, John Wiley & Sons, Inc., 1940. Price $3.75.

Electronic Structure and Chemical Binding, with special reference to inorganic chemistry, by Oscar Knefler Rice. 511 pages, illustrations, tables, 16 × 24 cms. New York, McGraw-Hill Book Company, Inc., 1940. Price $5.00.

A Short History of Science, by W. T. Sedgwick and H. W. Tyler. 512 pages, plates, illustrations, 15 × 22 cms. New York, The Macmillan Company, 1939. Price $3.75.

Statistical Method from the Viewpoint of Quality Control, by Walter A. Shewhart. 155 pages, illustrations, 17 × 25 cms. Washington, The Graduate School, Department of Agriculture, 1939.

Revista do Instituto do Ceara, Tomo LIII, Ano LIII, 1939. 262 pages, 16 × 23 cms. Fortaleza, 1939.

United States Department of the Interior, Bureau of Mines. Miners' Circular 39, Central Mine Rescue Stations, by J. J. Forbes, et. al. 55 pages, illustrations.

Technical Paper 600, Review of the Literature on the Construction, Testing, and Operation of Laboratory Fractionating Columns, by C. C. Ward. 36 pages, illustrations. Technical Paper 602, Inspection and Maintenance of Mine Hoisting Ropes, by L. C. Ilsley and McHenry Mosier. 27 pages, illustrations. Technical Paper, 605, Experiments on Strength of Small Pillars of Coal in the Pittsburgh Bed, by H. P. Greenwald, H. C. Howarth and Irving Hartmann, 22 pages, illustrations. 4 pamphlets, 15 × 24 cms. Washington, Government Printing Office, 1939.

National Advisory Committee for Aeronautics, Twenty-fifth Annual Report, 1939. 47 pages, 23 × 29 cms. Washington, Superintendent of Documents. Price 20 cents. Technical Notes: No. 744, The Development of Electrical Strain Gages, by A. V. de Forest and H. Leaderman. 51 pages, illustrations. No. 745, Tests of a Gust-Alleviating Flap in the Gust Tunnel, by Philip Donely and C. C. Shufflebarger. 24 pages, illustrations. No. 746, The Frequencies of Cantilever Wings in Beam and Torsional Vibrations, by C. P. Burgess. 13 pages, tables. No. 747, Propeller Rotation Noise Due to Torque and Thrust, by Arthur F. Deming. 18 pages, illustrations. No. 748, Principles, Practice, and Progress of Noise Reduction in Airplanes, by Albert London. 80 pages, illustrations. No. 749, A New Method of Studying the Flow of the Water Along the Bottom of a Model of a Flying-Boat Hull, by Kenneth E. Ward. No. 750, A Generalized Vortex Theory of the Screw Propeller and Its Applications, by Hans Reissner. 50 pages, illustrations. 7 pamphlets, 20 × 26 cms. Washington, Committee, 1940.

Bell Telephone System, Monographs: B–1180, The Toronto–Barrie Toll Cable, by M. J. Aykroyd and D. G. Geiger. 17 pages, illustrations. B–1182, Computation of Composite Noise Resulting from Random Variable Sources, by E. Dietze and W. D. Goodale, Jr. 19 pages, illustrations. B–1183, Load Rating Theory for Multi-Channel Amplifiers, by B. D. Holbrook and J. T. Dixon. 21 pages, illustrations. B–1184, The Quantum Physics of Solids—I, by W. Shockley. 79 pages, illustrations. B–1185, Dial Clutch of the Spring Type, by C. F. Wiebusch. 18 pages, illustrations. B–1186, Synthesis of Reactance 4-Poles, by S. Darlington. 97 pages, illustrations. B–1187, Theory of Secondary Emission, by D. E. Wooldridge. 43 pages, illustrations. B–1188, Metallic Bridges between Separated Contacts, by G. L. Pearson. 9 pages, illustrations. B–1189, Limiting Current Densities in Electron Beams, by J. R. Pierce. 23 pages, illustrations. B–1190, The Decamethylene Series of Polyesters, by C. S. Fuller and C. J. Frosch. 12 pages, illustrations. B–1191, Numerical Calculations of the Reflection of Electrons by Metals, by L. A. MacColl. 10 pages, illustrations. B–1192, The Solar Cycle and the F_2 Region of the Ionosphere, by W. M. Goodall. 8 pages, illustrations. B–1193, Molecular Weight of Sol and Gel in Crude Hevea Rubber, by A. R. Kemp and H. Peters. 20 pages, illustrations. B–1195, Geometric Aspects of Relativistic Dynamics, by L. A. MacColl. 20 pages, illustrations. 14 pamphlets, 15 × 23 cms. New York, Bell Laboratories, 1939.

CURRENT TOPICS.

The Invariant.—A. A. MERRILL. One of the problems of science is to discover what, if anything, remains unchanged when things are shaken up, so to speak. This is the hunt for "the invariant" going on all of the time in science, in which hunt Einstein was very successful recently, as for instance, his "world-event." I will give a simple illustration of an invariant. Suppose you have a map of a city and you crumble it to put it into the waste paper basket. If you measure distances and angles on that crumbled map with straight scales and flat protractors, you will find that the crumbling has altered such magnitudes so measured. Is there anything then that has not been altered? There is and in human living it is very important. No matter how you crumble the map if, on that map, you move a pencil along some street the "order" with which you pass the cross streets will not be altered. This "invariant order" holds for all crumblings provided you do not tear the map. In human living this "invariant order" appears as "the irreversibility of time," tearing the map being represented by death. One form of this phenomenon shows up in physics as "entropy," but note that this "invariancy" has meaning only for certain large frames of reference giving "universals" so to speak. In the local, here-now field of human living there is no invariancy, there is always change, evolution and growth except in those humans with ossified brains.

Now it is because humans constantly confuse these two entirely different aspects of reality (universal and local), that we have fighting between conservative and radical.

Air Puts Cavities in Building Materials.—A. M. HOFFMANN (*Compressed Air Magazine*, Vol. 44, No. 12). Within the past two years, many public buildings, apartment houses, industrial plants, theaters, etc., have been constructed abroad with materials and by a system that, apparently, is unknown on this side of the Atlantic. Its chief virtues are that it promotes speed of erection and that it saves weight through the extensive utilization of hollow flooring, as well as wall beams and columns. While hollow building materials as such are nothing out of the ordinary, the method by which they are now being produced is decidedly novel. It is known as the Bison pneumatic core system, which makes use of patented withdrawable

cores to form the cavities. This is now generally done by means of hollow clay bricks, which become an integral part of the structure and therefore represent an outlay that no longer enters into consideration. The cores are used over and over again. Bison concrete floors are either precast or cast in situ, depending on conditions. One way or the other, the cores are made up of one or more rubber tubes encased in canvas and are inflated with compressed air at a pressure of 5 pounds per square inch. Quantity production or precasting involves the use of molds, in which five floor or wall beams are manufactured at a time. For this purpose, the cores are wrapped in heavy Kraft paper to protect them and to facilitate extraction. When adequately expanded they are placed in the mold and secured at one end by a metal holding-down bar. If the members are subsequently to be coated with plaster, they are provided with keyways which are formed by 4-ply cord laid lengthwise on the floor of the mold and spaced about 3 inches apart. The cords are later stripped from the finished beams.

R. H. O.

Midwest Power Conference.—The tentative program of this Conference, to be held April 9–10, 1940, and sponsored by the Armour Institute of Technology in coöperation with other midwest colleges, universities and engineering societies, includes papers on power facilities, gas turbines, electrical transmission, industrial power plants for refineries, and paper mills, fuel problems of power plants, and hydro power. The program promises to be of wide range in details of these subjects.

R. H. O.

Use of Glued Laminated Arch Gains in Mid-West Building.—Wooden arches built of comparatively thin boards bent to shape in forms and glued together to make a single unit have given rise to a new and growing industry in the building field, according to Technical Bulletin No. 691, "The Glued Laminated Wooden Arch," published by the Forest Service, U. S. Department of Agriculture. The key of this development is the glued laminated arch ordinarily made by bending a one-inch board into a curve in a bending device and then bending and gluing other and similar boards to it, lengthwise and one by one, by means of pressure applied with clamps. These built-up wooden arches are used for supporting the roofs of large halls, churches, barns, etc. Spans of 100 feet or more can be used with excellent architectural effects. The arches can be built up to larger cross sections and greater lengths than are usually

employed in wood construction, and a considerable percentage of material can be utilized that is too small to be structurally useful otherwise. Although this type of construction has been used with success in Europe for about one-third of a century, even such structures as vehicular bridges and railroad sheds being satisfactorily built with this kind of arch, T. R. C. Wilson, author of the bulletin and senior engineer of the Forest Products Laboratory at Madison, Wisconsin, cites the construction of the service building of the Laboratory in 1935 wherein 7 glued, laminated arches were installed, as the beginning of the present increasing use of the built-up arch in this country. Since then, about 100 buildings or halls of the same general type or construction have been built in mid-western States, including churches, community halls, gymnasiums, garages, dance halls and Gothic-styled dairy barns. The arches used vary widely in design.

R. H. O.

Program to Demonstrate Use of Cotton in Paper Making Announced.—The Division of Marketing and Marketing Agreements of the Department of Agriculture has announced a demonstrational program under which a small quantity of low-grade cotton will be used in the manufacture of high-quality paper. The program provides for purchase by the Writing Paper Manufacturers' Association of lint cotton, spinnable waste, and cotton linters for use in the manufacture of fine writing paper and other papers of similar type. Part of the cost of the raw materials used to carry on the program will be borne by the Department of Agriculture and part by the Association. The share to be borne by each will be determined when the types and kinds of cotton fibers to be used are definitely agreed upon. Participation in the program will be open to eligible manufacturers, whether or not they are members of the Association. "If actual use under the program demonstrates to manufacturers the feasibility of using lower priced cotton fibers in making fine paper," J. B. Wyckoff, Chief of the Marketing Section, said, "an opportunity for expanding markets for such paper should be afforded. Such a development would create an outlet for substantial quantities of additional raw materials which normally compete with higher grade spinning cotton and constitute a price-depressing element in normal trade channels."

R. H. O.

Last Year Temperatures Generally Above Normal.—A review of last year's weather shows only 1 month, February, that could be definitely classed as having abnormally low temperatures, when

the country as a whole is considered, says J. B. KINCER, of the United States Weather Bureau. All other months were either moderately warm or had large plus departures from normal temperature. January 1939 was abnormally warm everywhere, with the greatest abnormalities in the Northwest. February was relatively cold west of the Mississippi River, but warmer than normal in eastern sections. March had above-normal temperatures everywhere, except in a small northeastern area. April was warmer than normal from the Great Plains westward and in southeastern sections, but moderately cool in the Mississippi and Ohio Valleys and Lake region. May had above-normal temperatures everywhere, except in the Southeast. June was moderately cool in the extreme Northeast and Northwest, and warmer than normal in other sections. July had above-normal temperature everywhere, except locally in the East. August was generally warmer than normal, except in a small southeastern area. September had above-normal temperatures everywhere, except locally in the Southwest, the extreme South, and extreme Northeast. October had relatively warm weather in all sections, except very locally in the central-north and Northeast. November was warmer than normal over about two-thirds of the country, but was slightly cooler than normal in the Atlantic area and the South. December, as a whole, was outstandingly warm in practically all parts of the country.

R. H. O.

National Advisory Committee for Aeronautics, Twenty-Fifth Annual Report, 1940.—This report is for the fiscal year 1939. It summarizes the work of the Committee for the Congress of the United States. During the past year important progress was made in many ways in providing, through the Committee's researches at Langley Field, new knowledge which should be the basis of extensive improvements in our aircraft. Discovery during the past year of a new principle in airplane-wing design may prove of great importance. The transition from laminar to turbulent air flow over a wing was so delayed as to reduce the profile drag, or basic air resistance, by approximately two-thirds. It is too early to appraise adequately the significance of this achievement. So far, its application is limited to small airplanes but there are indications of its ultimate applicability to larger airplanes through continued research. It should increase the range and greatly improve the economy of airplane operation. As the Committee reviews the effects of scientific research on the progress of aeronautics

during the last quarter of a century, it is convinced that the systematic conduct of scientific research is the most fundamental activity of the Government in connection with the development of aeronautics. Because of the increasing relative importance of aeronautics in national defense and in transportation, the Committee believes that the needs of the country justify a further immediate expansion of research activities in two directions, namely, the establishment of an engine research laboratory, and additional stimulation of aeronautical research in educational and scientific institutions.

R. H. O.

Bells—Concerning Their Tones.—D. T. JAMES. (*Mechanical Engineering*, Vol. 62, No. 2.) By all who have heard a good set of bells, well played, the beauty and charm of carillon music will be acclaimed. Any project designed to increase further the popular enjoyment of this instrument through attempting to perfect it by eliminating its faults, may then be considered worth while. The author has set himself a problem in the improvement of the carillon. In reality, the exact knowledge of bells is so meager as practically to preclude the use of a word implying such a degree of exactitude as does "science." Bellmaking is still largely an art depending upon rule-of-thumb methods and skill of the craftsman. The metal from which bells are made is a bronze, which is cast into a specially designed pattern and then cleaned. After this, it invariably needs tuning which is done by removing metal from different sections. Believing that the first purpose of an investigation for the improvement of bells should be the exact proportions of a bell to produce a given strike tone and to produce overtones harmoniously in tune with and properly in proportion to it—not to determine the faults of present bells—an account of an experimental procedure carried out at Michigan State College is given. Conclusions to be drawn from the data obtained are few and speculations many. It is concluded that a large number of experiments on a greater number of less dispersed variations would, in all probability, give a curve from which it would be possible to obtain a mathematical result. This would of course require the expenditure of a great deal of time, money, and painstaking effort, but the author believes that the research would prove profitable in tuning time saved and even in the necessity for any tuning. Further, it is deemed best that, upon further experiment, the pouring temperature of the metal be kept within very closely defined limits, as it affects the density of the resultant metal.

R. H. O.

Whip Stress in a Locomotive Main Rod at 100 Miles per Hour.—Railway trains which operate at sustained speeds approaching a hundred miles per hour are rapidly increasing in number. Because of this trend M. W. Davidson of Vermillion, South Dakota, was encouraged to make a detailed study of the flexural or "whip" stress which develops in a locomotive I-section main rod and also follow this with an examination of the total tensile stress which results when the whip stress is combined with that due to the inertia of the reciprocating parts, the fraction of the main rod itself, the steam force, and the component of the normal guide reaction which is due to the inertia of the rod. Mr Davidson's paper was presented as a contribution of the Railroad Division A. S. M. E. at their recent annual meeting and is published in the *Transactions of the A. S. M. E.*, Vol. 62, No. 2. The particular connecting rod, reciprocating weights, general dimensions, and quantities used in the study are from a class F–3, Chicago, Milwaukee, St. Paul and Pacific locomotive, having cylinders 23 in. in diameter and 28 in. stroke; driving wheels 79 in. in diameter; reciprocating parts weighing 1126 lb.; I-section connecting rod, 116 ½ in. between wrist-pin and crank pin centers, and weighing 877 lb. The results of the study show that for 100 m.p.h. the maximum whip stress that can be expected in a conventional I-section locomotive main rod is of the order of 8500 lb. per sq. in., and that the maximum combined tensile stress will be of the order of 14,000. As the elastic limit of the usual carbon steel of which these rods are made is about 48,000 lbs. per sq. in., the factor of safety with this as base is about 3.5. If 3½ per cent. nickel steel of the same carbon content were used for the rod material, the elastic limit would be about 60,000 and the factor of safety with this as base would be 4.38.

R. H. O.

Radioactive Standards.—A series of radioactive standards are being prepared under the direction of the Committee on Standards of Radioactivity of the National Research Council. This work is being supported in part by a generous grant from the American Philosophical Society to the Massachusetts Institute of Technology. The standards under preparation at present are radium standards, thorium standards, standard rock samples. The samples of rock will be analyzed for radium and thorium content and are intended for use as working standards to check methods used in extraction of radon and thoron from rock samples. They may be used for direct fusion in the electric furnace or for carbonate fusion. All of the samples will be analyzed at a number of laboratories equipped to make such measurements and ultimately certificates will be

issued by the National Bureau of Standards. This work is in progress but will require considerable time for its completion so that final figures are available only for part of the samples at the present time. Accurate knowledge of the radioactive content of the materials of the earth's crust is of primary importance in many phases of geology, geophysics and cosmology. Reliable radioactive standards are also essential in studies of radium and thorium poisoning and in biological and medical investigations using the technique of radioactive indicators, or internal artificial radioactivity therapy. For the latter purposes calibrated standard sources of β-rays will be made available. It is hoped that the standards which have been prepared by the Committee will provide all workers in these fields with a common basis for comparison of measurements and also improve the accuracy of all measurements of this type. It is likely that they will have other applications and the Committee would appreciate hearing from interested persons who may desire similar standards for their work. The Committee is also glad to cooperate as far as possible in aiding investigators to use these standards to the best advantage and welcomes specific inquiries regarding their use. It is urged that any suggestions regarding other desirable radioactive standards, not at present available, be submitted promptly to the Committee. In particular, it will facilitate the work of the Committee if those laboratories and individuals which can make use of these standards advise the Committee of their probable requirements. Communications may be addressed to the Chairman, Professor Robley D. Evans, Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts.

R. H. O.

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